NASA-EP-260
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TO URANUS AND BEYOND

(NASA-EP-260) TO URANUS AND BEYOND (Jet Propulsion Lab.) 28 p CSCL 03B

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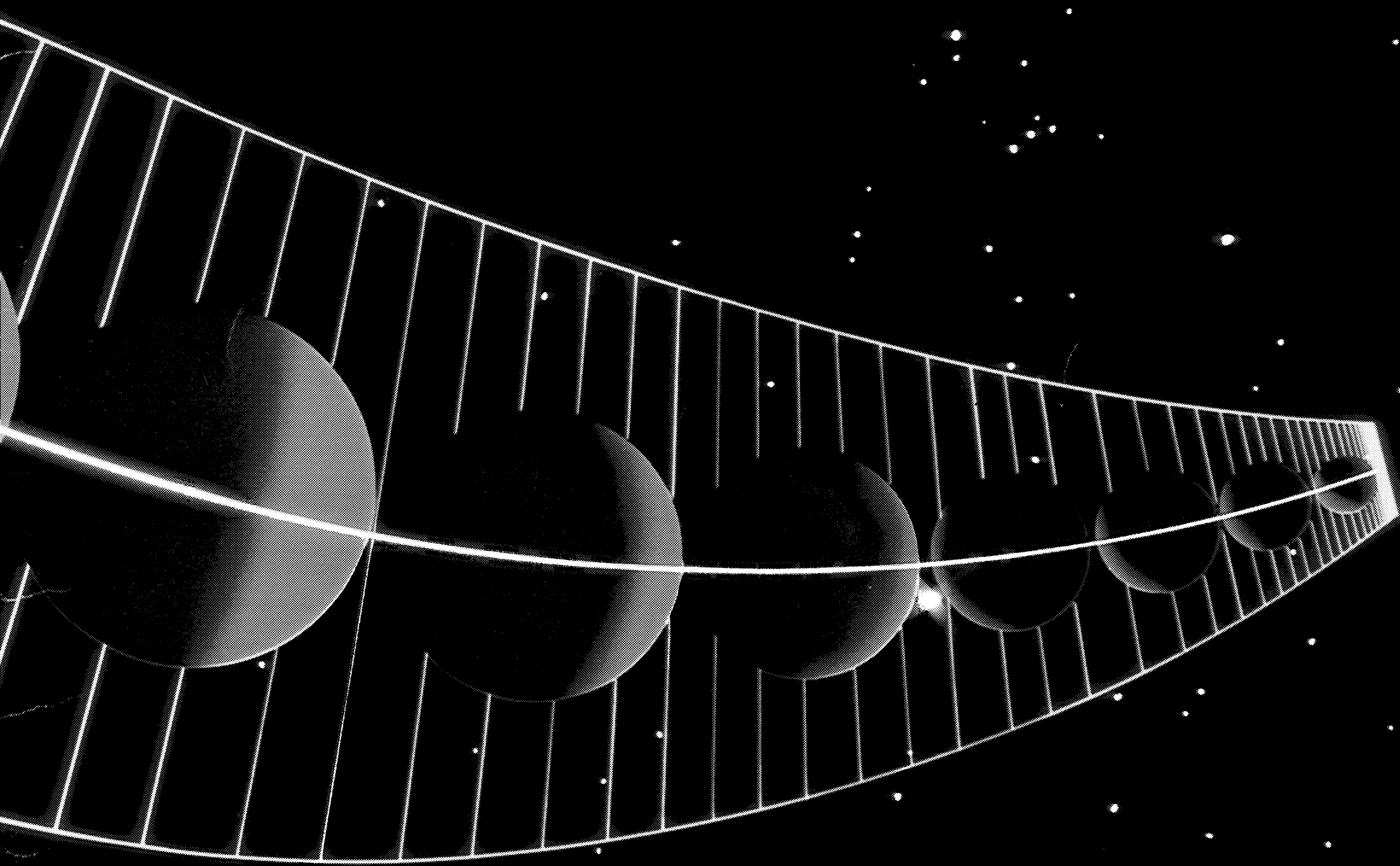


Uranus is out of kilter with the rest of the solar system. Its pale-blue face masks a planet with bizarre characteristics.

The seventh planet from the Sun, Uranus is tipped on its side, probably shoved into that position eons ago by a collision with some passing planet-sized body.

Beneath the serene cloud tops exists a deep layer of water mixed with hydrogen and helium, under which lies a partially molten, rocky core. The water, under tremendous pressure, is highly electrically conductive and is believed responsible for generating Uranus' oddly skewed magnetic field, which takes the shape of a corkscrew extending millions of miles into space behind the planet.

Another Uranian oddity is that despite the uneven distribution of sunlight hitting the planet, Uranus maintains a fairly even distribution of heat. For example, the equatorial region, which on the average receives the least sunlight, is about the same temperature as the polar regions.

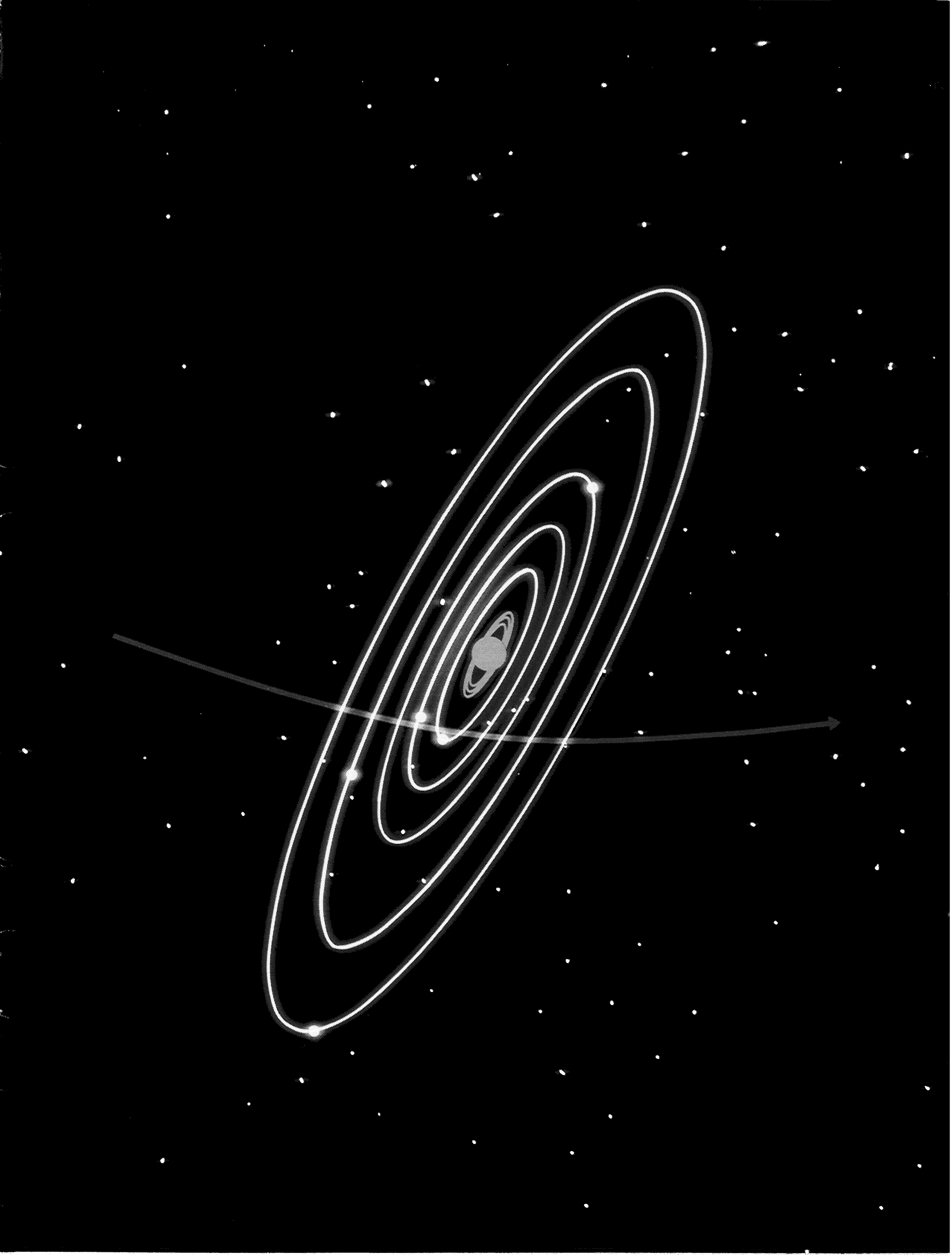
The Uranian rings, fewer than half of which are circular, are composed of disorderly black chunks of unknown composition, quite unlike the small, icy-bright particles that form Saturn's rings.

The Uranian moon Miranda, scarred by turmoil from within and without, may be a reconstituted moon, a hodgepodge of moon pieces ripped apart and randomly stuck back together like pieces of clay.

At a distance of nearly three billion kilometers (almost two billion miles) from Earth, the Voyager 2 spacecraft sent back this intriguing portrait of a planetary system dramatically altered by a violent past, one that remained hidden behind Uranus' bland countenance until Voyager's encounter in January 1986.

Cover: Uranus, backlit by the Sun, is seen as it looked to the departing Voyager 2; the spacecraft's view approaching Uranus is seen on the back cover. The outer curves bound the edges of the ring system, while the vertical green lines represent the apparent slant of the rings as observed by Voyager at various times during encounter. The white line traces the planet's center, as seen by Voyager 2, against the background of stars. From such information, scientists selected stars to use in occultation experiments, measuring the planet's atmosphere and rings.

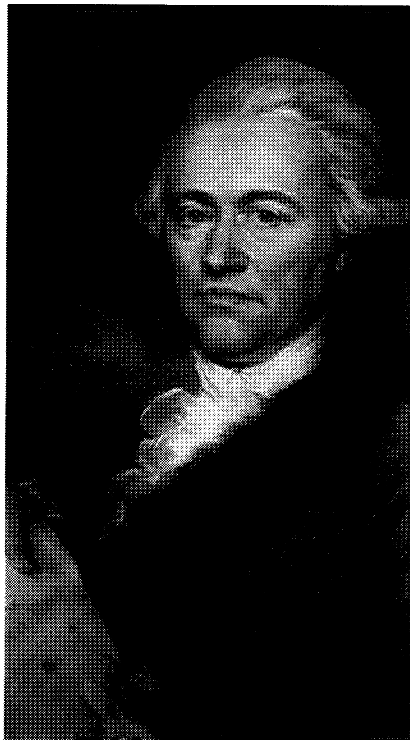
Right: The relative positions of the Uranian moons during the Voyager 2 flyby are shown. From innermost out, they are Miranda, Ariel, Umbriel, Titania, and Oberon.



Uranus is so far away that light takes two hours and 45 minutes to travel from there to Earth. Voyager 2, flying at an average velocity of 48,000 kilometers an hour (30,000 miles an hour), took eight-and-a-half years to get there.

Uranus cannot be seen with the naked eye except on a clear, moonless night. Ancient observers did not record the planet, which remained unreported until amateur astronomer William Herschel discovered it in 1781 with the aid of a powerful, homemade telescope. (As a result, Herschel soon shed his amateur standing to become one of the giants of astronomy.)

At first sighting, he believed the object to be a comet. Astronomers and mathematicians, however, calculated that its motion described an orbit around the Sun that no comet would follow. Two months after discovery, Uranus was decreed to be a planet—the first discovered with a telescope.



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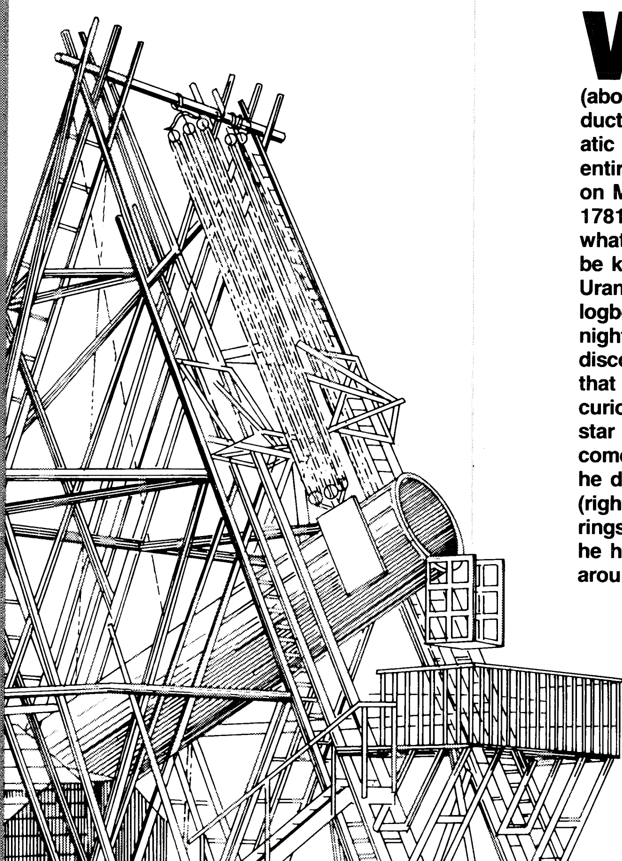
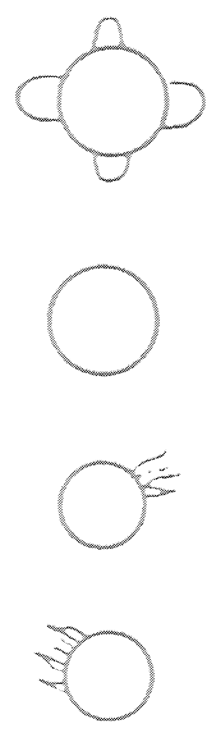
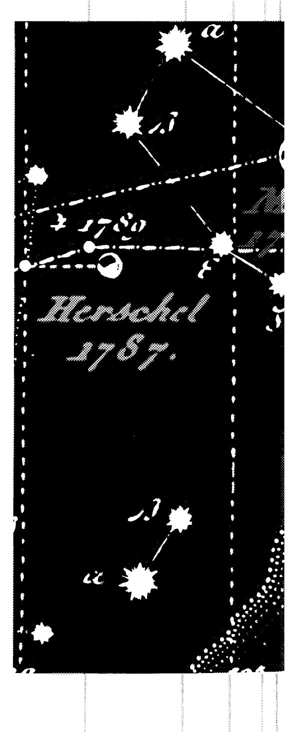
... in the quartile near ζ Tauri the lowest of two is a curious either Nebulous Star or perhaps a Comet.



William Herschel (above) was conducting a systematic survey of the entire sky when, on March 13, 1781, he observed what was later to be known as Uranus. In his logbook on the night of the discovery he wrote that he'd seen "a curious nebulous star or perhaps a comet." In 1789, he drew pictures (right) of the stubby rings he thought he had glimpsed around the planet.





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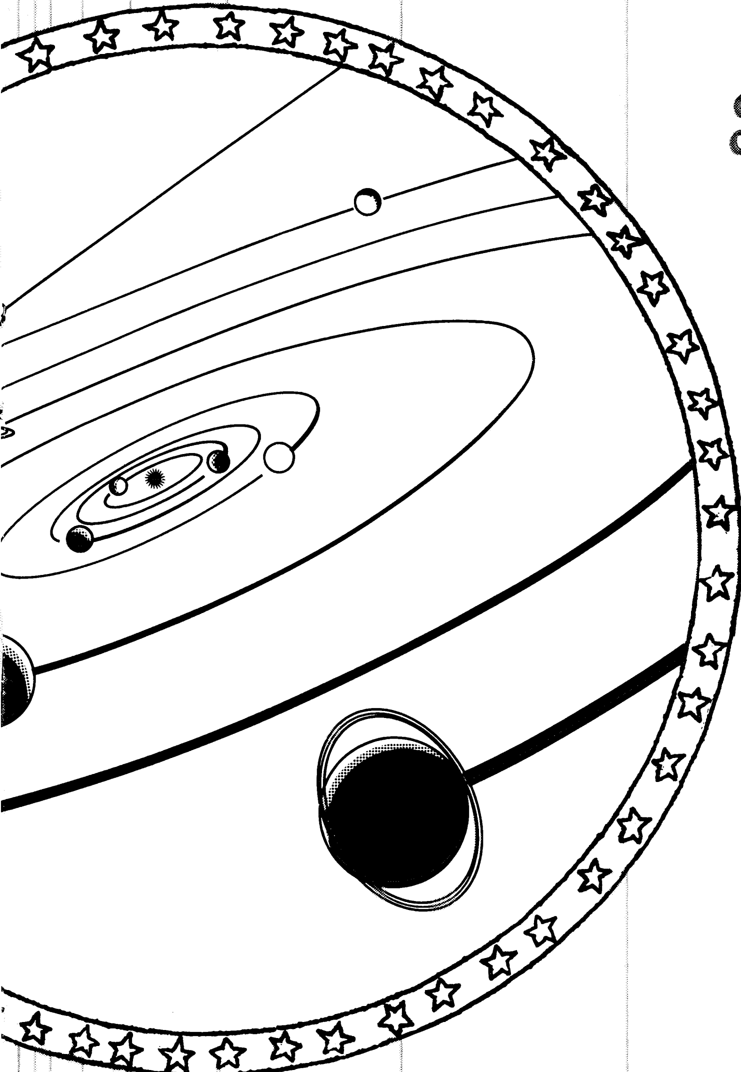
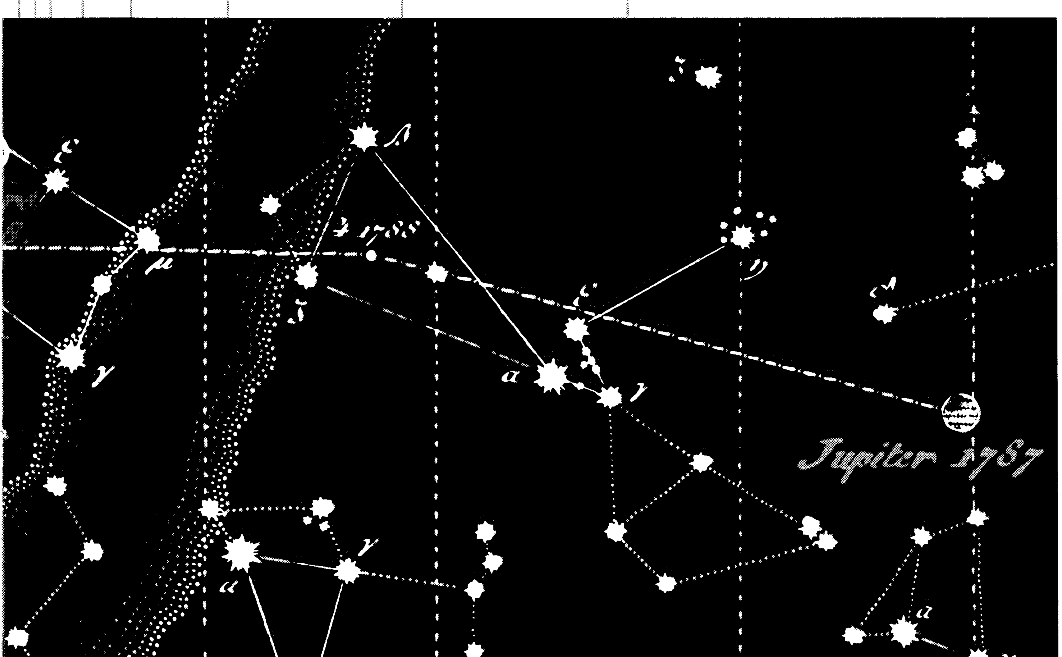


Before the discovery of Uranus, the known solar system ended at Saturn's orbit (far left), as compared with the solar system we know today (left).

For more than 200 years—until Voyager 2's flyby—hazy views of the planet were the best scientists could obtain from even the most powerful telescopes on Earth. Only the broadest of characteristics could be discerned. Uranus was known to be tipped over on its side, to have an atmosphere that contained hydrogen, and to be surrounded by at least nine black rings and five dark, medium- to small-sized moons. Scientists theorized that the planet's atmosphere also included helium and gaseous compounds of carbon, nitrogen, and oxygen. A layer of melted ice was thought possibly to exist beneath the deep, bluish atmosphere. It was not known whether Uranus had a magnetic field at all. Scientists would have one chance in this century to answer their questions about the seventh planet from the Sun.

Over the decades following Uranus' discovery, observers noted an irregularity in its motion that showed it was being tugged at by the gravitational field of something even farther away from the Sun. This suggested to mathematicians the existence of another planet beyond Uranus. The orbit of an eighth planet was calculated and predicted. Sixty-five years after the discovery of Uranus, Neptune became the first planet to be discovered through mathematical calculation.



This 18th century engraving (left) shows the relative positions of Jupiter, Mars, and "Herschel," as Uranus was provisionally known.

PREPARING VOYAGER

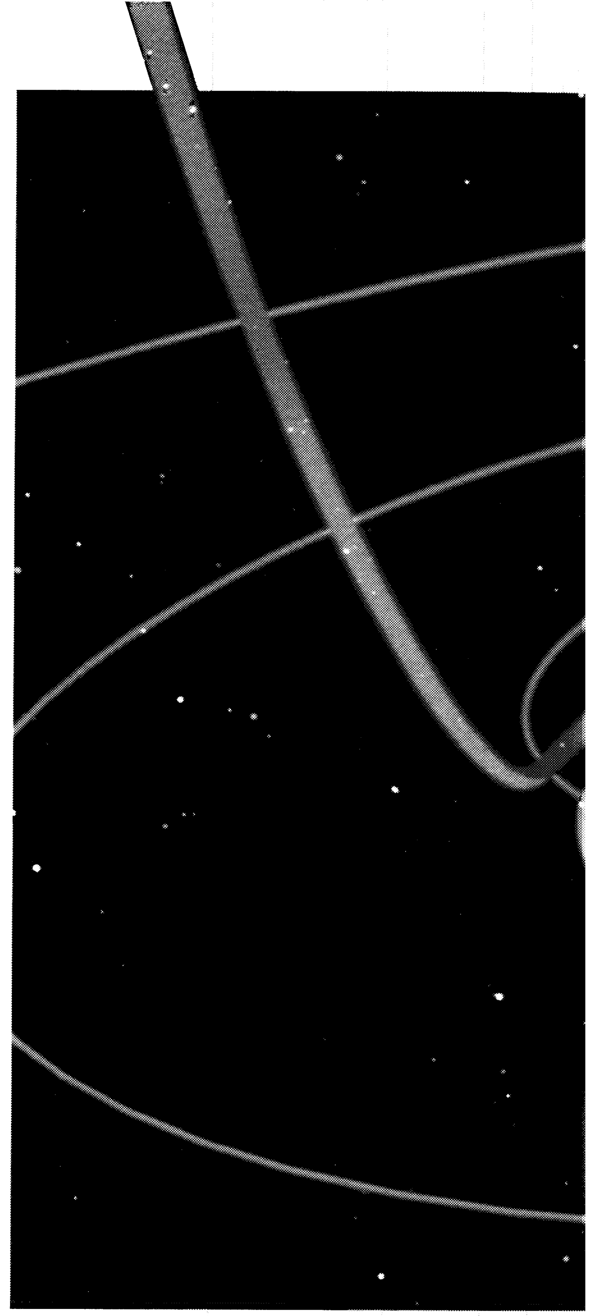
When building the Voyager 1 and 2 spacecraft for the National Aeronautics and Space Administration (NASA) at the Jet Propulsion Laboratory (JPL) in the mid-1970s, mission engineers and scientists were aware of the opportunity before them—the four largest planets formed a pattern that would allow a spacecraft, using "gravity-assist" techniques, to fly past them and most of the 32 moons they were then known to collectively possess. The same fortuitous arrangement of the planets would not occur for another 175 years, and, without using gravity assist, it would take a spacecraft 30 years to get to Uranus.

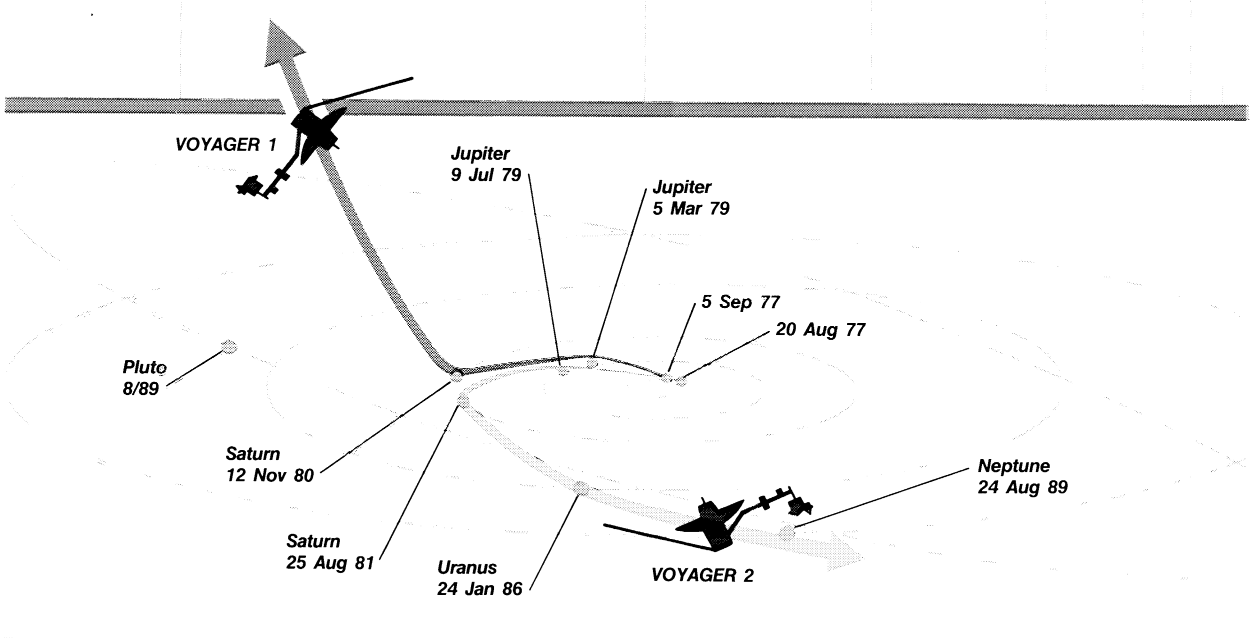
As tempting as the opportunity may have been, the effort would have required the development of expensive new technology. Budget constraints prevailed and the four-planet "Grand Tour" mission idea was shelved. The planetary itinerary for the Voyager spacecraft, though still ambitious, would be limited to Jupiter and Saturn.

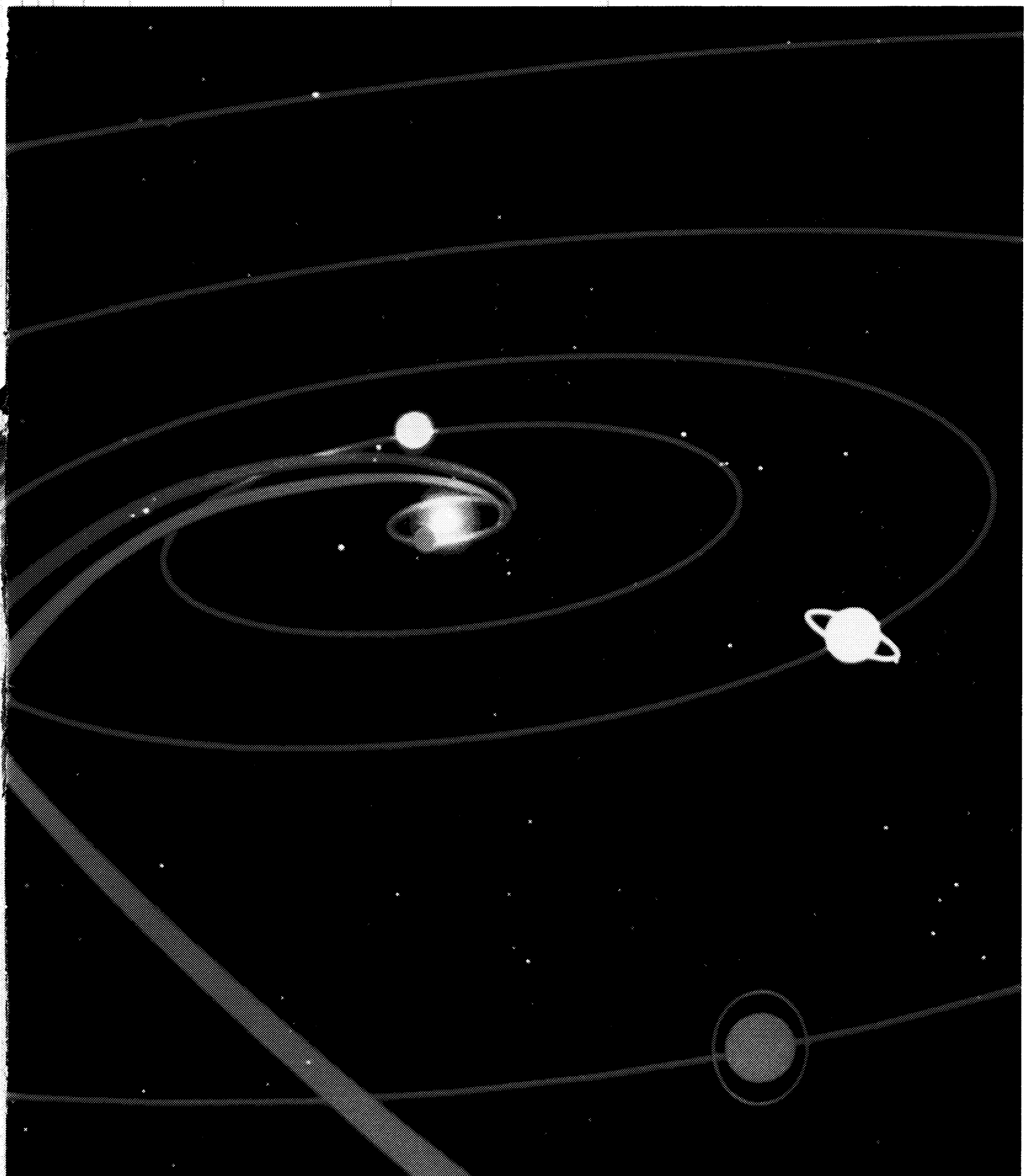
Built to the specifications of the mission they were funded to fly, the Voyager spacecraft were designed to last four years and outfitted to study just Jupiter and Saturn and their moons. No special equipment was to be put on board for Uranus or Neptune encounters. According to approved Project plans, the Voyager missions would end in late 1981, with continued operation of the two spacecraft left in question.

Despite the lack of funding, a firm plan, or a full understanding of the ability of the spacecraft to conduct Uranus and Neptune encounters, Voyager officials at NASA and JPL kept those options open. Their hope was that funding would catch up with Voyager 2 as it flew across the solar system.

Funding for the Uranus leg of the mission was authorized in 1981, and for the Voyager Neptune encounter in 1985.







As Voyager flies farther away, its signal received on Earth gets weaker. By lowering the rate at which the spacecraft transmits data, Voyager engineers increased the time devoted to the transmission of each bit of information, akin to speaking slowly to be better understood; less is said, but what is said has a better chance of being heard clearly. The normal trade-off for getting high-quality data from Voyager at Uranus would, therefore, be to reduce the amount of data transmitted. Voyager scientists, however, needed both high-quality data and lots of it. To accomplish this, imaging—the bulkiest of the data—would have to be squeezed down for transmission to Earth. Each picture would have to be described in fewer words.

The techique that allows Voyager to travel from one planet to the next is called "gravity assist." As Voyager neared Jupiter, for example, the spacecraft came under the influence of that planet's gravity. This affected Voyager's flight path in two ways. First, as Jupiter's gravity drew the spacecraft closer to the planet, Voyager's velocity increased. Jupiter also pulled the spacecraft off its relatively straight course, so that it flew in a curve around Jupiter toward a rendezvous with Saturn. In this way, the orbital motion of one planet is used to increase the spacecraft's velocity, and the gravitational field of the planet is used to redirect the spacecraft's course to the next planet. It was this gravity-assist technique that made the idea of multiple-planet missions at all feasible with the early 1970's technology available to Voyager's designers.

Voyager 1 embarked on a journey into unexplored space above the plane of the solar system after its Saturn encounter in 1980. Voyager 2 was directed from Saturn to Uranus, and will encounter Neptune in 1989.

First, engineers enhanced Voyager 2's capabilities by radioing new software to the spacecraft. The new programming enabled one computer, which had served as a backup to another, to be devoted to compressing and formatting all imaging data prior to transmission.

Each Voyager picture frame consists of 800 lines, with each line containing 800 picture elements, called pixels. Eight bits of data are required to describe each of the 256 shades of gray possible for each pixel. Thus each image could require up to 5.12 million bits of data to be described. Instead of measuring the absolute level of gray in each pixel, however, only the absolute level in the first pixel of each line is transmitted, followed by the difference in brightness between each successive pixel in that line. This way, many fewer bits of data are needed to rebuild a Voyager picture on the ground. The process allowed the spacecraft to return thousands, instead of hundreds, of pictures from Uranus.

One Voyager data management process on the spacecraft encodes data in a way that allows computers on Earth to reconstruct transmissions that have been garbled by interplanetary radio interference.

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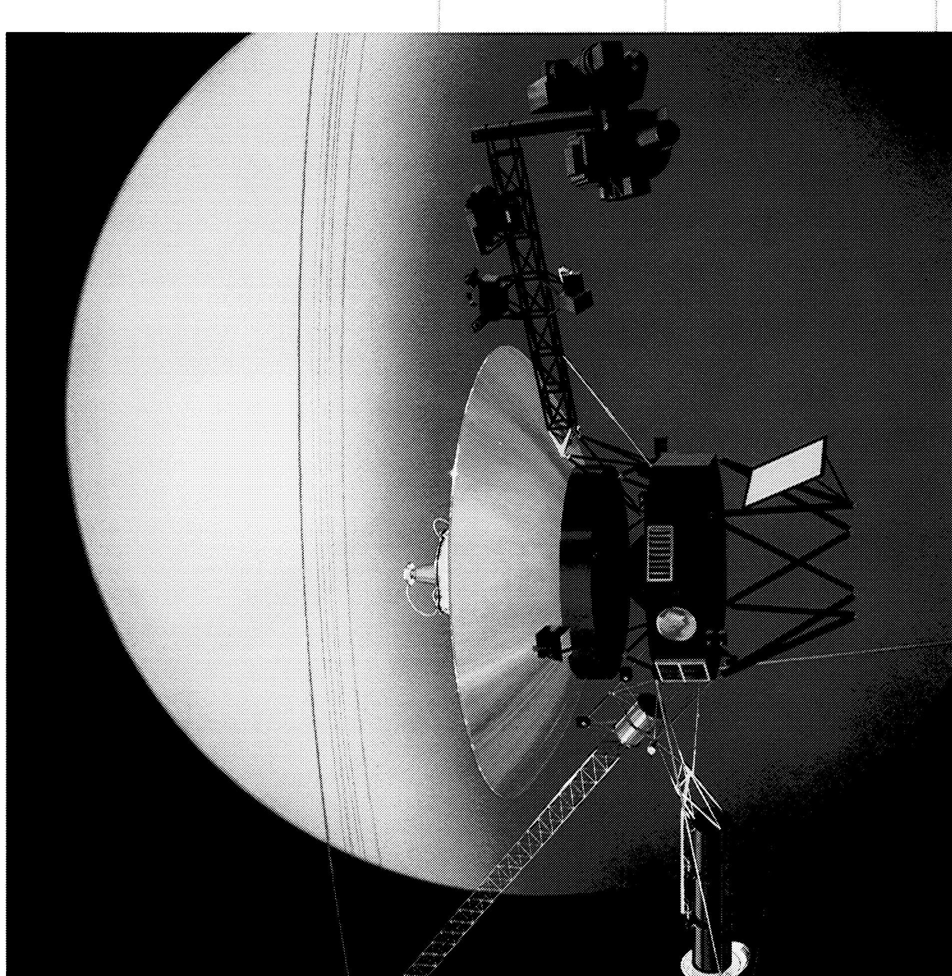
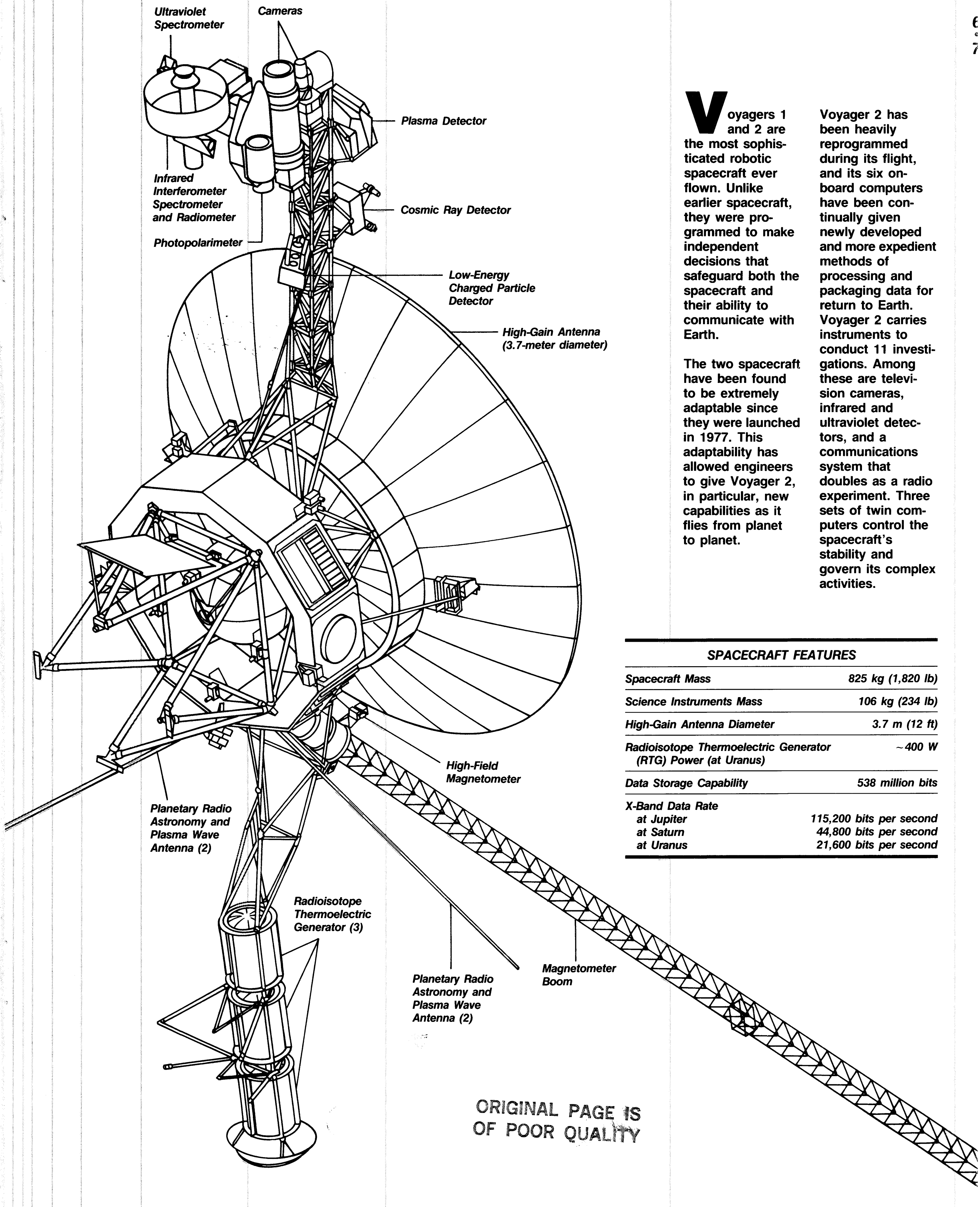
Voyager 2 has had a few mechanical problems on its journey of more than five billion miles.

The spacecraft's first major problem was the total failure of one of its two radio receivers. The remaining receiver works, despite suffering a reduction in the range of frequencies that it can "hear" to only a thousandth of its original design capability. In the event that Voyager's remaining radio receiver might fail altogether, Voyager engineers have set aside a corner of the spacecraft's computer memory for what is called the "back-up mission load." This is a load of computer commands that would instruct Voyager to carry out rudimentary investigations on its own if the radio receiver failed.

The second major problem affecting Voyager 2 occurred in 1981. The movable instrument platform jammed in one of its two axes, preventing pointing of the mounted instruments. Engineers later determined that the jamming was caused by a loss of lubricant and the consequent damage to a bearing in the high-speed section of the gear chain, precipitated by repeated high-speed movement of the platform during the busy Saturn encounter. The platform began moving again when commands were sent two days after it jammed. It performed flawlessly, but at intentionally low speeds, during the Uranus encounter.





Voyagers 1 and 2 are the most sophisticated robotic spacecraft ever flown. Unlike earlier spacecraft, they were programmed to make independent decisions that safeguard both the spacecraft and their ability to communicate with Earth.

The two spacecraft have been found to be extremely adaptable since they were launched in 1977. This adaptability has allowed engineers to give Voyager 2, in particular, new capabilities as it flies from planet to planet.

Voyager 2 has been heavily reprogrammed during its flight, and its six on-board computers have been continually given newly developed and more expedient methods of processing and packaging data for return to Earth. Voyager 2 carries instruments to conduct 11 investigations. Among these are television cameras, infrared and ultraviolet detectors, and a communications system that doubles as a radio experiment. Three sets of twin computers control the spacecraft's stability and govern its complex activities.

SPACECRAFT FEATURES

Spacecraft Mass	*825 kg (1,820 lb)*
Science Instruments Mass	*106 kg (234 lb)*
High-Gain Antenna Diameter	*3.7 m (12 ft)*
Radioisotope Thermoelectric Generator (RTG) Power (at Uranus)	*~400 W*
Data Storage Capability	*538 million bits*
X-Band Data Rate	
at Jupiter	*115,200 bits per second*
at Saturn	*44,800 bits per second*
at Uranus	*21,600 bits per second*

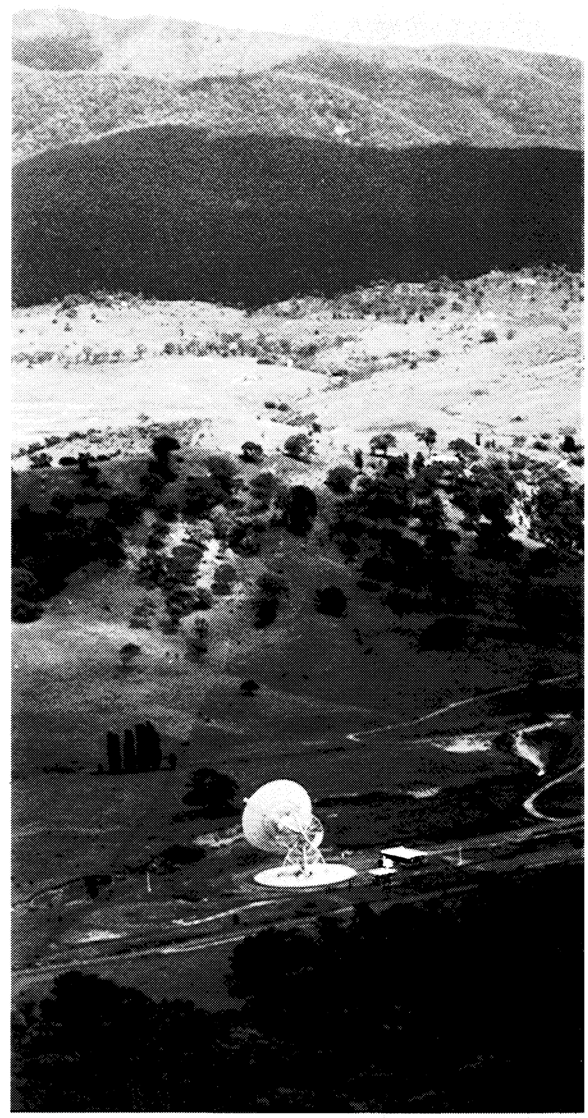
With the Golay encoding technique used during the first six years of the mission, an equal number of bits of encoding information were added to each package of data returned. A characteristic of JPL spacecraft is redundancy—the existence of backup or alternate systems to function in lieu of any critical components that may fail. To protect against a variety of possible failures in Voyager's data and communications hardware, an additional encoding device, a Reed-Solomon encoder, was placed on the spacecraft. Voyager engineers had no previous experience with the device, but it did offer the advantage of requiring only one-sixth the number of appended bits needed by the Golay system.

By the time Voyager 2 passed Saturn, the need for Reed-Solomon encoding had not arisen. But it was obvious that Reed-Solomon would be more efficient than Golay encoding for sending information back from distant Uranus and Neptune. Since the Reed-Solomon scheme produced fewer bits to encode the data Voyager collected, a much greater amount of data from Uranus was returned than would have otherwise been possible.

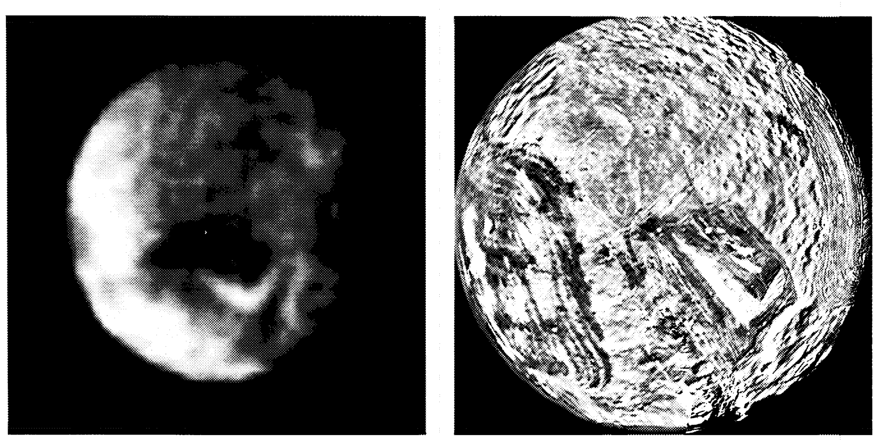
Dusk on Earth is brighter than noon on Uranus. The Voyager 2 cameras were not designed to operate with such low light levels, so techniques were developed to allow the cameras to take clear pictures of dimly lit, moving objects—the Uranian moons—from the speeding spacecraft.

One technique was to have the cameras track their targets while making long exposures. The entire spacecraft was rotated with the camera's shutter open for exposures as long as 15 seconds. This difficult engineering feat yielded sharply focused close-ups of Miranda and the other Uranian moons.

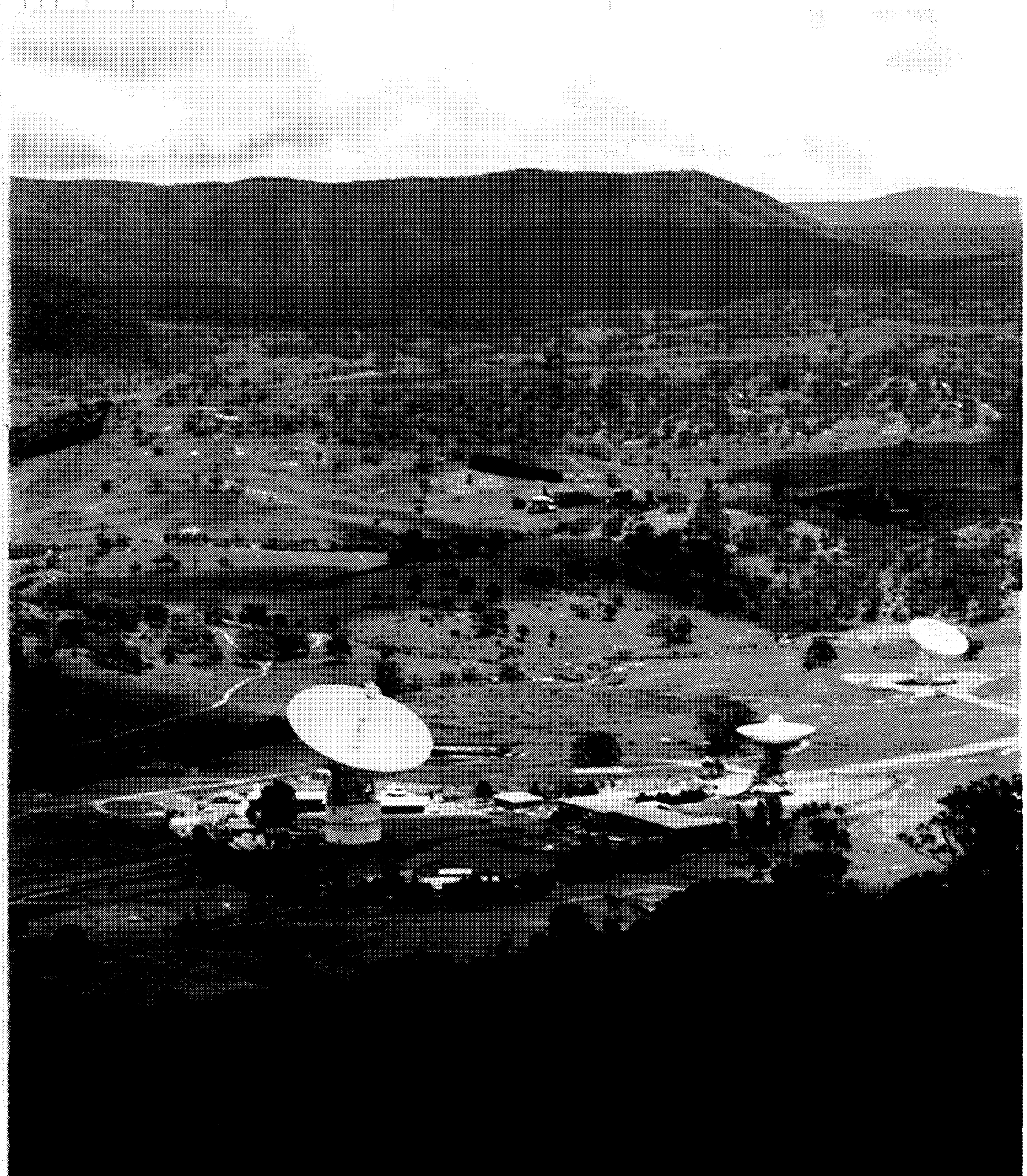
Other situations called for the cameras to be as motionless as possible for exposures of up to 96 seconds. In this effort, Voyager engineers managed to slow the spacecraft's inherent "wobble" to one-twentieth the rate at which an hour hand moves on a clock.



The DSN's antenna site in Canberra, Australia provided critical coverage during the Uranus encounter.



Images of Miranda (right) taken with and without measures to reduce smear are compared, showing the obvious clarity gained by turning the spacecraft while the camera shutter was open.



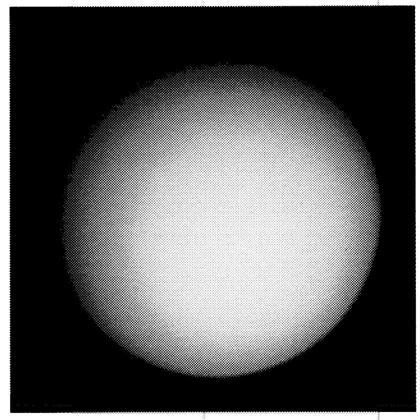
All the information to be returned by Voyager from Uranus wouldn't be useful if it couldn't be received clearly on Earth. The 64-meter (210-foot) antennas of JPL's Deep Space Network (DSN), among the world's largest, weren't big enough to separate the Voyager data from radio "noise" in the spacecraft's transmissions.

To solve the problem, DSN engineers electronically linked two or more antennas together in a technique called antenna arraying. This reinforces the strength of the received signals in the same way that a single, larger dish would. Arraying's biggest payoff came in Australia, whose government provided its Parkes Radio Astronomy Observatory 64-meter antenna to be linked with the DSN's three-antenna complex near Canberra. The most critical events of the encounter, including Voyager's closest approaches to Uranus and its moons, were designed to occur when the spacecraft would be transmitting to the complex in Australia. The data were successfully relayed to JPL through this array.

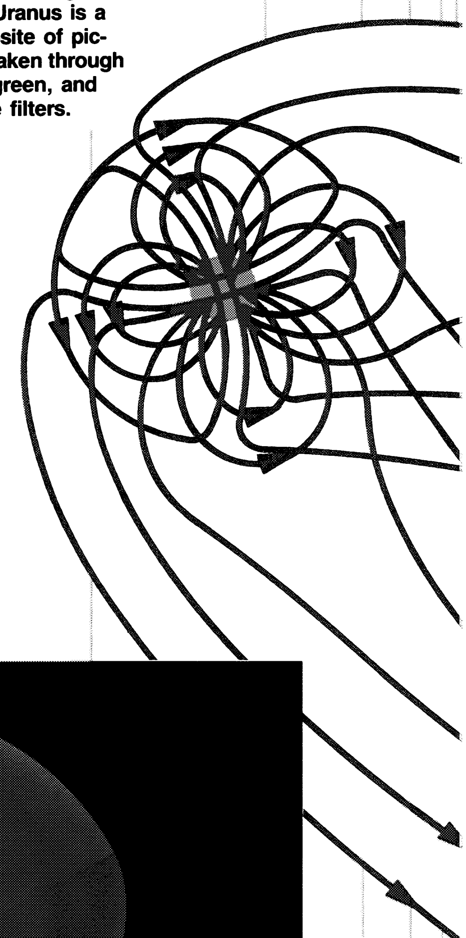
"If it weren't for the imaging experiment, we wouldn't even know the planet is there," lamented one scientist less than 15 days before Voyager was to make its closest approach to Uranus. No radio noise, like that emitted from Jupiter and Saturn, could be heard. Nothing unusual appeared in data from the ultraviolet and infrared instruments. No evidence of a magnetic field had been observed. Even the pictures of Uranus returned by Voyager's cameras hadn't changed substantially. The planet, still a hazy blue sphere, only grew larger in the field of view of Voyager's cameras. Voyager scientists called it "the fuzzy blue tennis ball." This was a planet that would not readily give up its secrets. Whatever it had to offer, as Voyager would find, it would hold until the last possible minute. But what the Uranian system did finally yield makes it one of the strangest collections of planet, moons, and rings in the solar system.

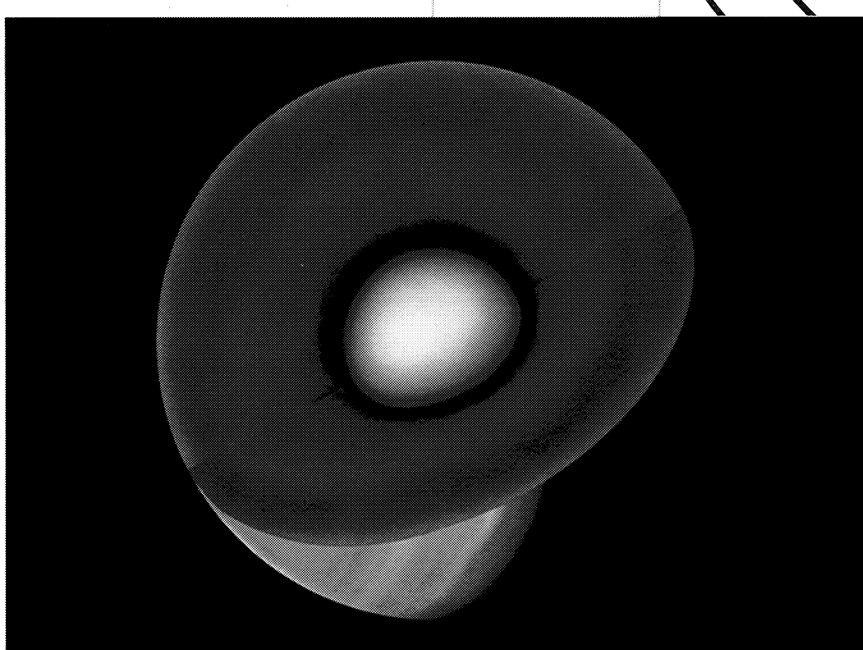
Voyager supplied the first big piece of the Uranian puzzle when it discovered the planet's substantial magnetic field, comparable in strength to the fields around Saturn and Earth. Planetary magnetic fields are thought to be generated by fluid motion in a planet's core (molten iron in Earth's core, for example). While Uranus is believed to have a partially molten core, the core is not big enough to generate, by itself, the magnetic field Voyager observed. Voyager scientists now believe that the field is produced instead by electrically conducting water deep within the Uranian atmosphere. (At one time, scientists thought that Uranus' relatively abundant water was concentrated in a deep ocean.)

This atmospheric water is quite unlike anything on Earth: it is hot [10,500° Celsius (8,000° Fahrenheit)] and under such great pressure that it becomes highly electrically conductive. It would require a pressure a few million times that at Earth's surface to produce the same effect on Earth.



This image of Uranus is a composite of pictures taken through blue, green, and orange filters.





Deep within Uranus' interior (right) is a partially molten core. Atop that core are cloud layers of ammonia, water, methane ice, and, finally, hydrogen and helium.

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The offset axis (top) of the Uranian magnetic field results in an oddly shaped magnetic tail that twists behind the planet (left).

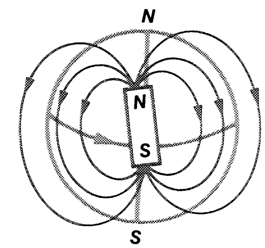
Voyager scientists looked for, and finally found, the elusive Uranian magnetic field. What was unexpected was the orientation of that field, tilted from the planet's axis of rotation by 60 degrees and offset from it by one-third of Uranus' radius. As at Earth and other planets with magnetic fields, Uranus' field is swept back into a long tail by the wind of charged particles that streams from the Sun. The odd tilt of the magnetic field, however, coupled with the fact that the planet's axis of rotation points toward the Sun, has the effect of twisting the tail into an unusual corkscrew shape that spirals in sync with Uranus' 17.24-hour rotation period.

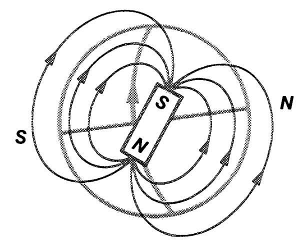
Voyager found radiation belts at Uranus of an intensity similar to those at Saturn, although they differ in composition. The radiation belts at Uranus appear to be dominated by hydrogen ions, without any evidence of heavier ions (charged atoms) that might have been sputtered from the surfaces of the moons. Uranus' radiation belts are so intense that irradiation would quickly darken any methane trapped in the icy surfaces of the moons, possibly contributing to the dark appearance of their surfaces.

At the top of Uranus' atmosphere is a relatively uniform layer of hydrogen and helium. Beneath this layer, Voyager found clouds of methane ice. Scientists believe that farther down, clouds of ammonia and water may also exist.

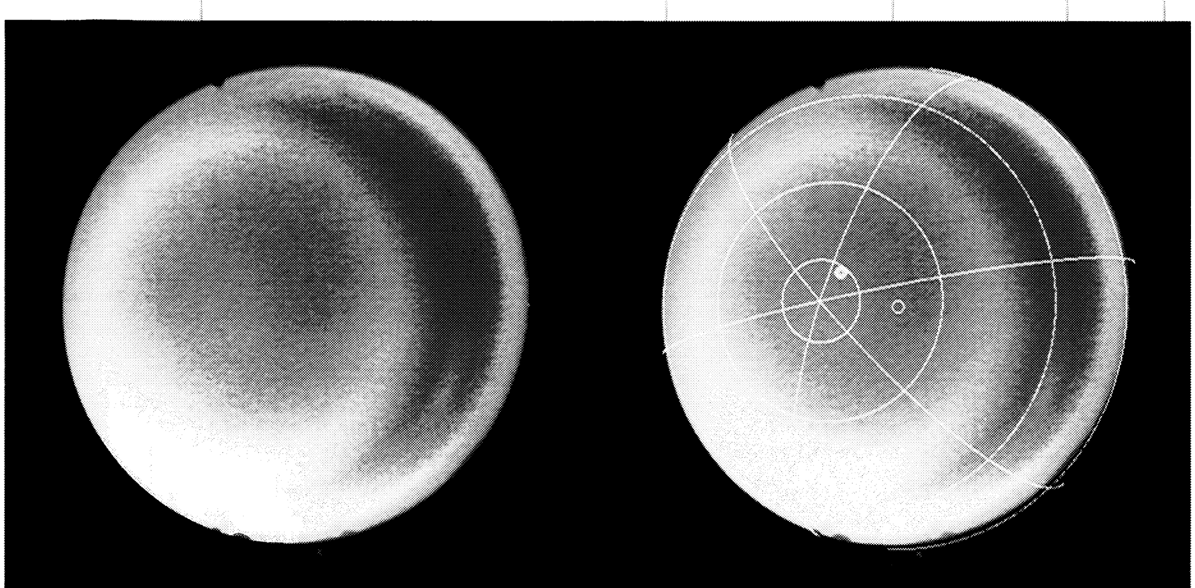
The fact that Uranus contains a large proportion of melted methane ice reveals much about the neighborhood of the solar system in which it formed. The planets formed from the remnants of the solar nebula left over from the formation of the Sun. Silicon and iron aggregated into globes. In the inner solar system, the planets from Mercury to Mars were too small to attract and hold gases like hydrogen and helium. But in the outer solar system, the giant planets Jupiter and Saturn, with their powerful gravitational fields, attracted and held thick atmospheres dominated by these two gases.

Some of the most abundant material existing two billion miles from the Sun was water ice. Uranus apparently drew upon this frozen material, building up a layer of melted ice which was then covered with an atmosphere of hydrogen and helium. Thus, Uranus is denser than Jupiter and Saturn, and has a thinner atmosphere and a different internal structure.

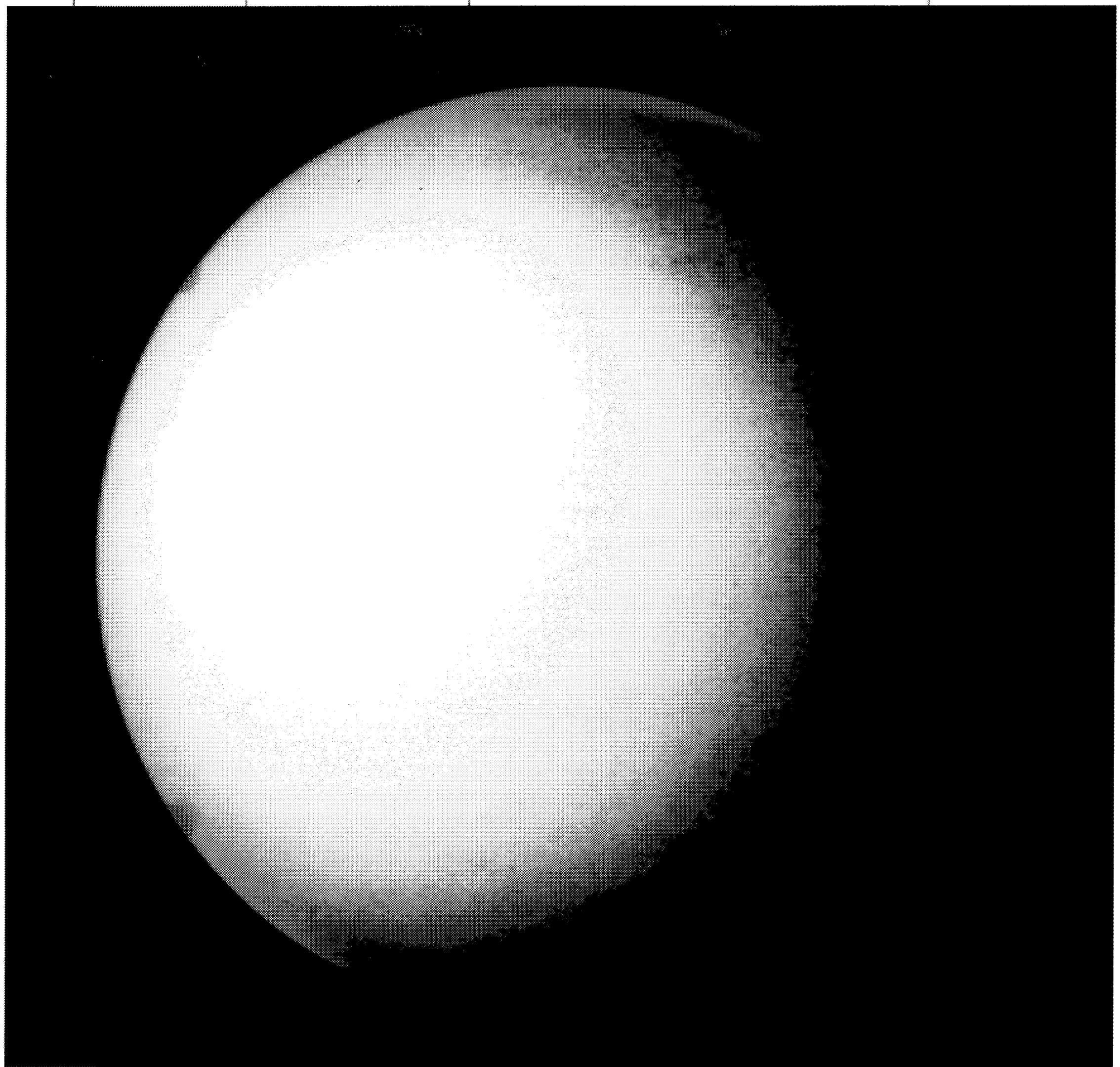




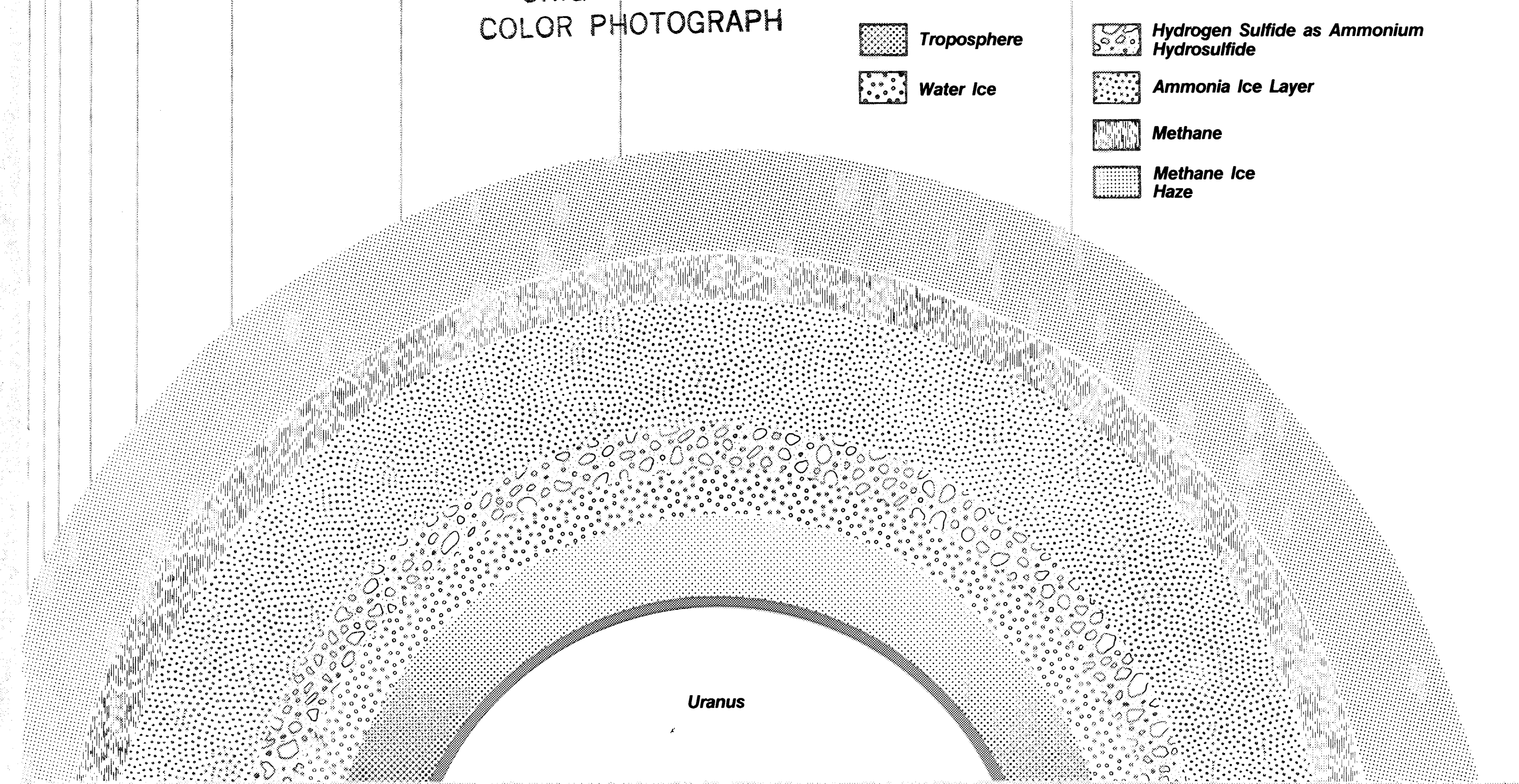
Jupiter's magnetic field (top), indicative of other planets, illustrates just how unusual Uranus' magnetic field (bottom) is.



Images of Uranus were combined and processed to enhance variations in the planet's atmosphere. A superimposed latitude-longitude grid shows the atmosphere circulates in the same direction as the planet rotates.



Special image processing was applied to this picture of Uranus to enhance the high-level haze in the planet's upper atmosphere.

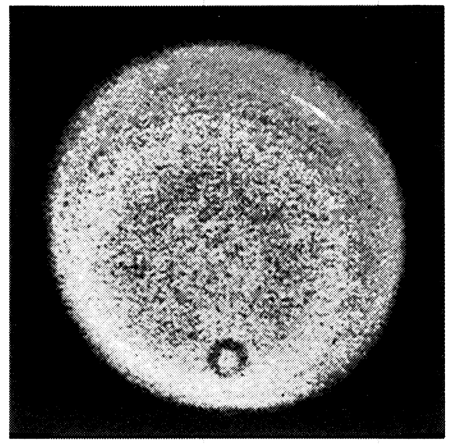


Unlike the other giant planets, Uranus possesses an internal heat source that is quite small. Infrared measurements from Voyager indicate that Uranus has a virtually uniform temperature of −214° Celsius (−353° Fahrenheit). This is especially strange because the polar regions receive more sunlight than the equatorial regions, and the equator should therefore be colder. Some unknown mechanism is equalizing the temperature of the Uranian atmosphere from pole to equator.

Voyager's ultraviolet instrument found that the entire southern (Sun-facing) hemisphere glows, a phenomenon scientists have dubbed "electroglow." It results from some unknown process that also produces an extended corona of dissociated hydrogen molecules surrounding the planet.

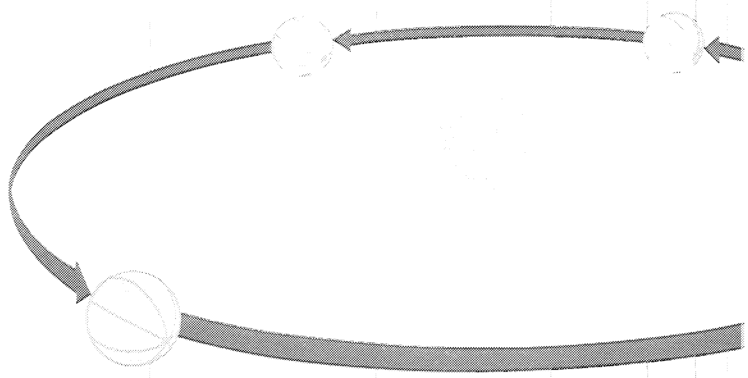
Through a telescope, Uranus appears a uniform powder blue. By exaggerating the colors of faint features in the atmosphere, however, Voyager scientists discovered latitudinal banding on Uranus, further enhancing the planet's "bull's-eye" appearance. This was an important finding in atmospheric physics, because it shows that rotation and not sunlight determines the motion of a planet's atmosphere.

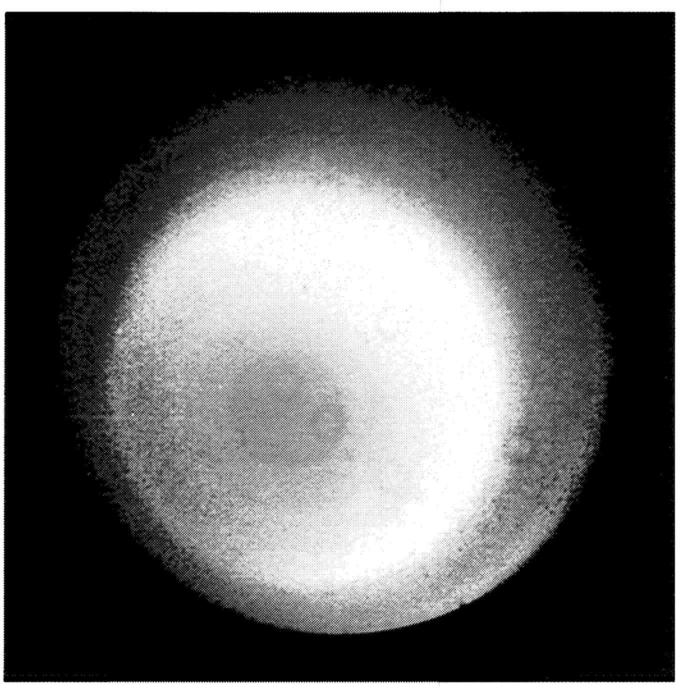
The few small clouds discerned in the Uranian atmosphere were enough to allow scientists to determine wind velocities on the planet on the order of 40 to 160 meters per second (90 to 360 miles per hour); on Earth jet streams blow at about 50 meters per second (110 miles per hour).



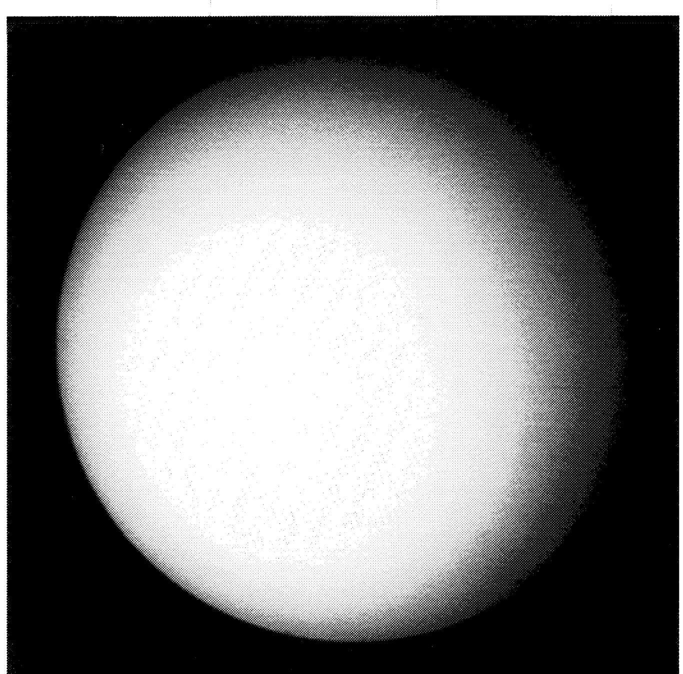
A faintly visible cloud (the bright streak) was enhanced to facilitate atmospheric motion measurements.

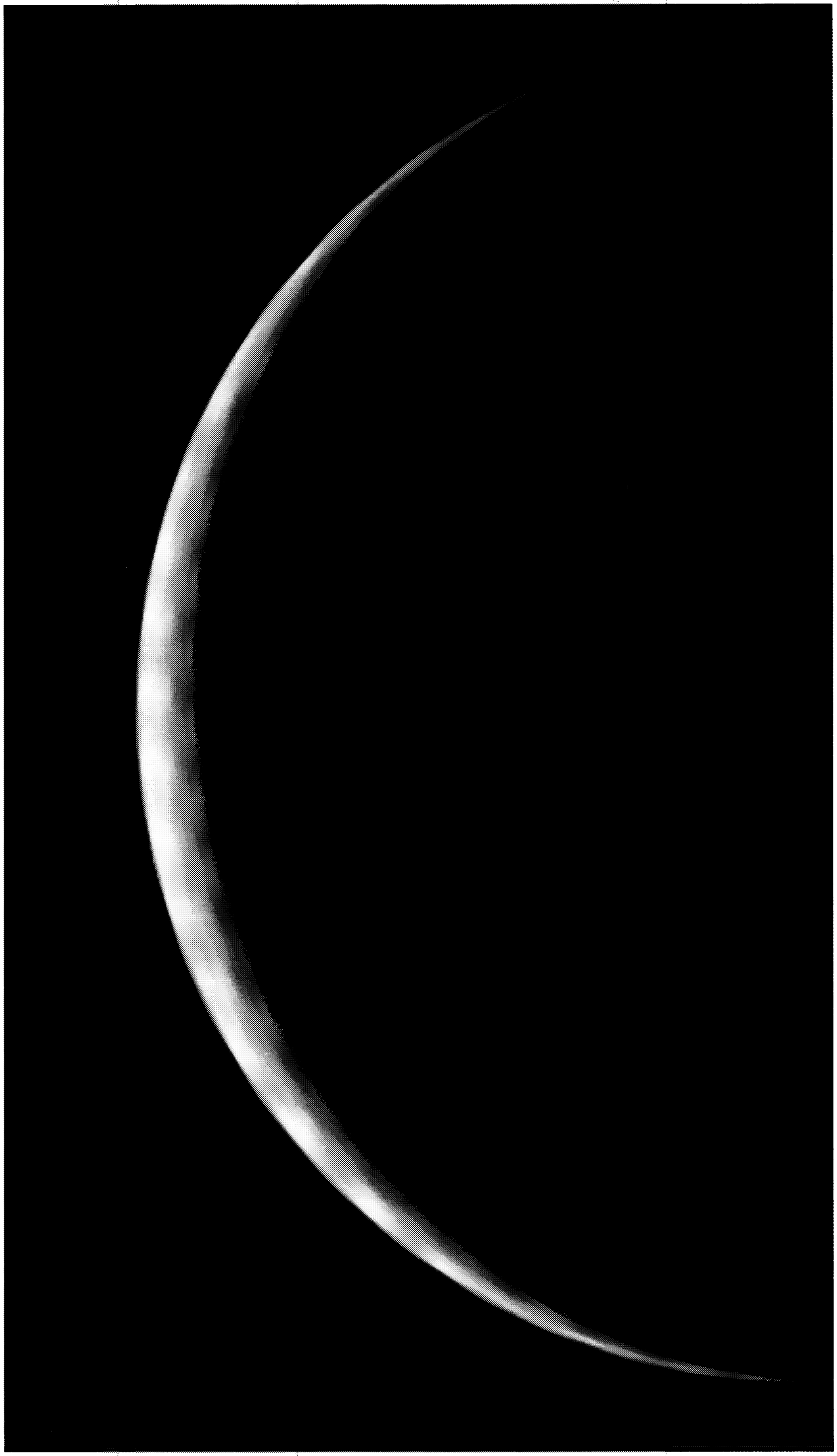
Seasons on Uranus last approximately 21 years, as different hemispheres face the Sun.





The picture at right shows Uranus as human eyes would see it, a uniformly blue planet. Computer image-processing techniques were applied to the picture above to bring out the subtle contrast between latitudinal bands.





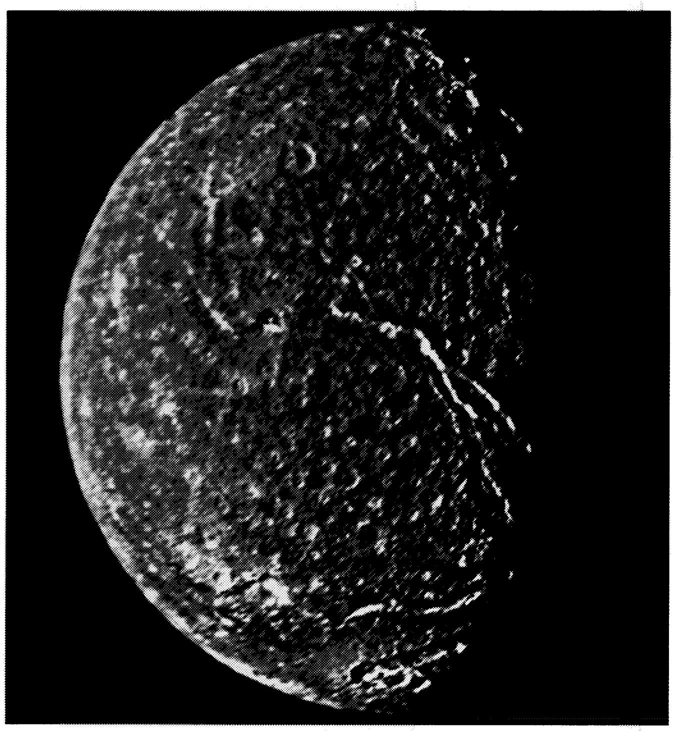
Voyager was one million kilometers (about 600,000 miles) beyond Uranus when it acquired this view of the planet's sunlit crescent.

THE MOONS

Voyager photographed each of the five large moons of Uranus known before the encounter: from the innermost out these are Miranda, Ariel, Umbriel, Titania, and Oberon. Ten additional moons were discovered by Voyager. The largest of the new moons is about 170 kilometers (110 miles) in diameter.

Titania is marked by huge fault systems and canyons that indicate some degree of geologic activity in its history. Ariel appears to have undergone a period of even more intense activity leading to many fault valleys and flows of melted methane ice.

Umbriel is ancient and dark, apparently having undergone little geologic activity. Large craters pockmark its surface, undisturbed since they were formed. The outermost of the pre-Voyager moons, Oberon, is also heavily cratered, with little evidence of internal activity other than some dark material covering the floors of several of the craters.



Titania is the largest of Uranus' moons and shows long, deep fault valleys across its surface.

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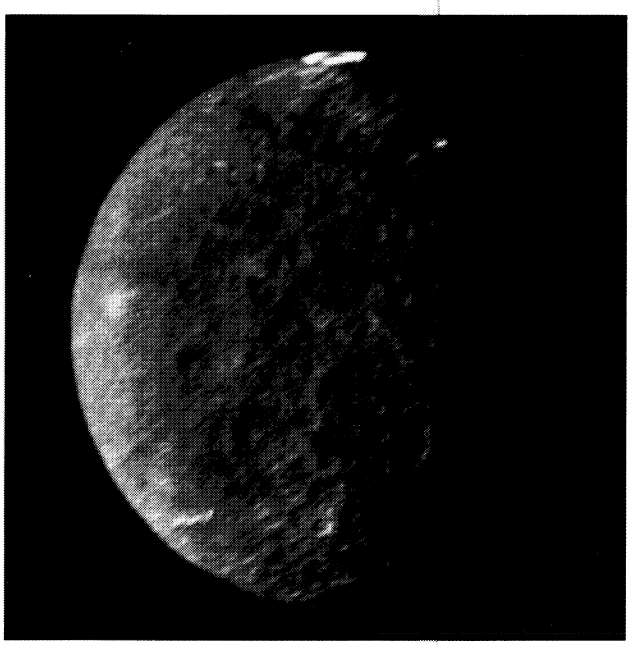
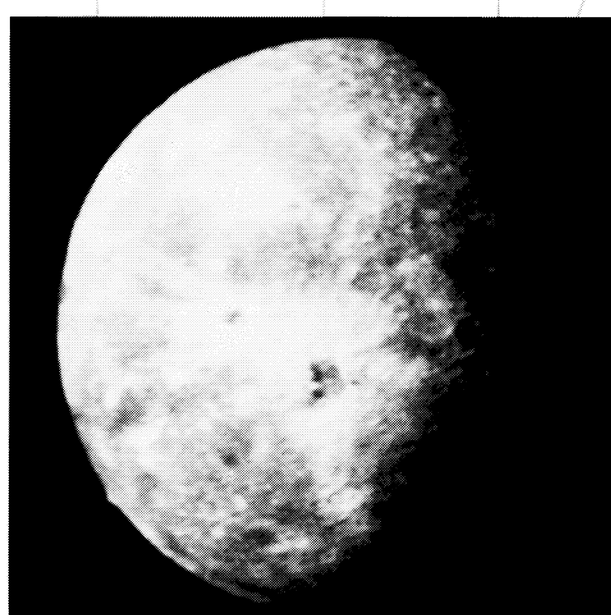
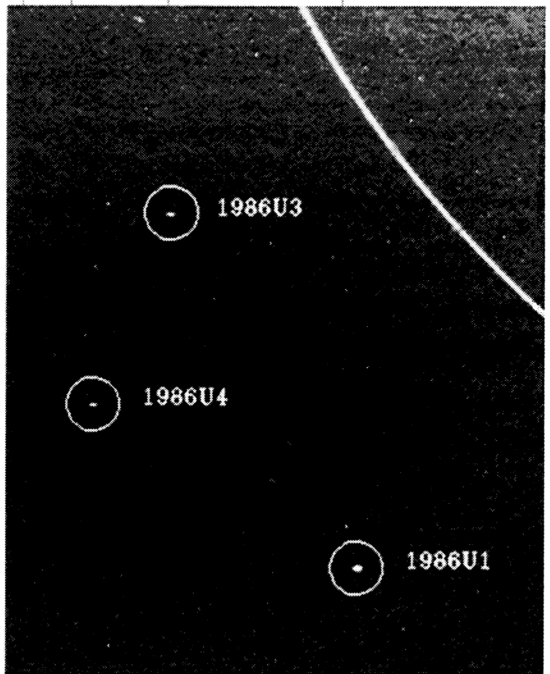


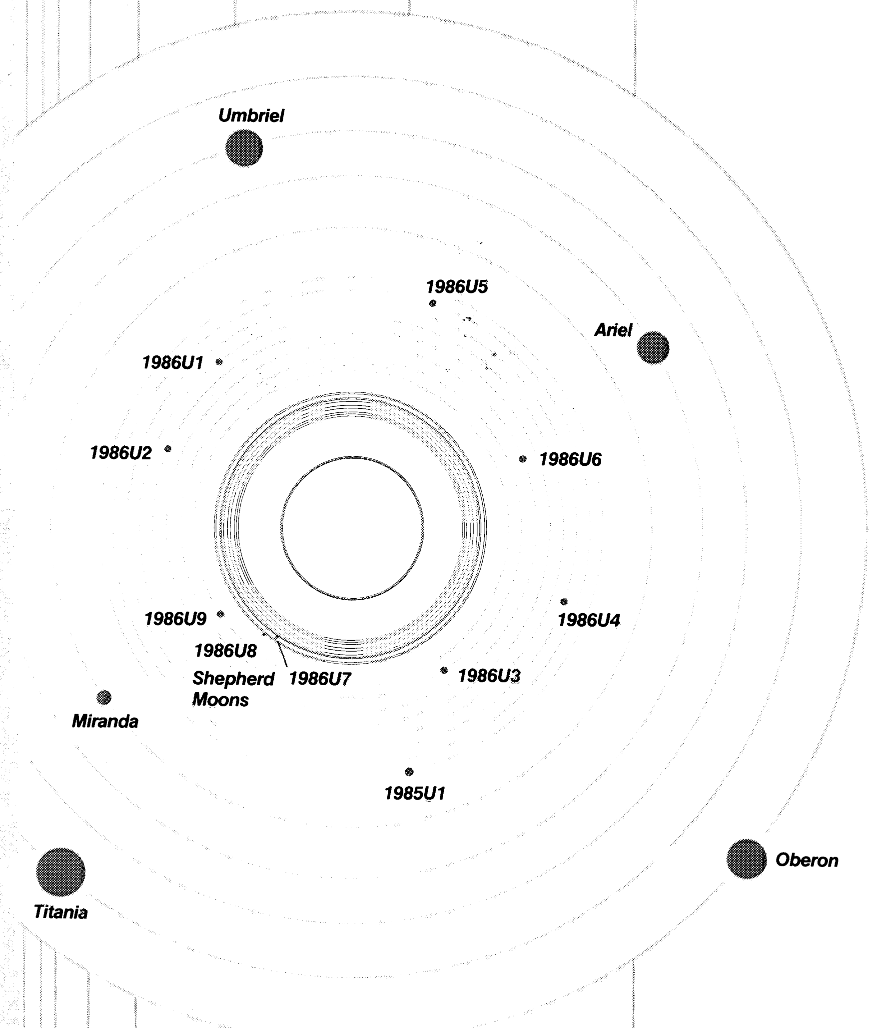
Umbriel's southern hemisphere displays heavy cratering. The face of this dark moon indicates a low level of geologic activity.

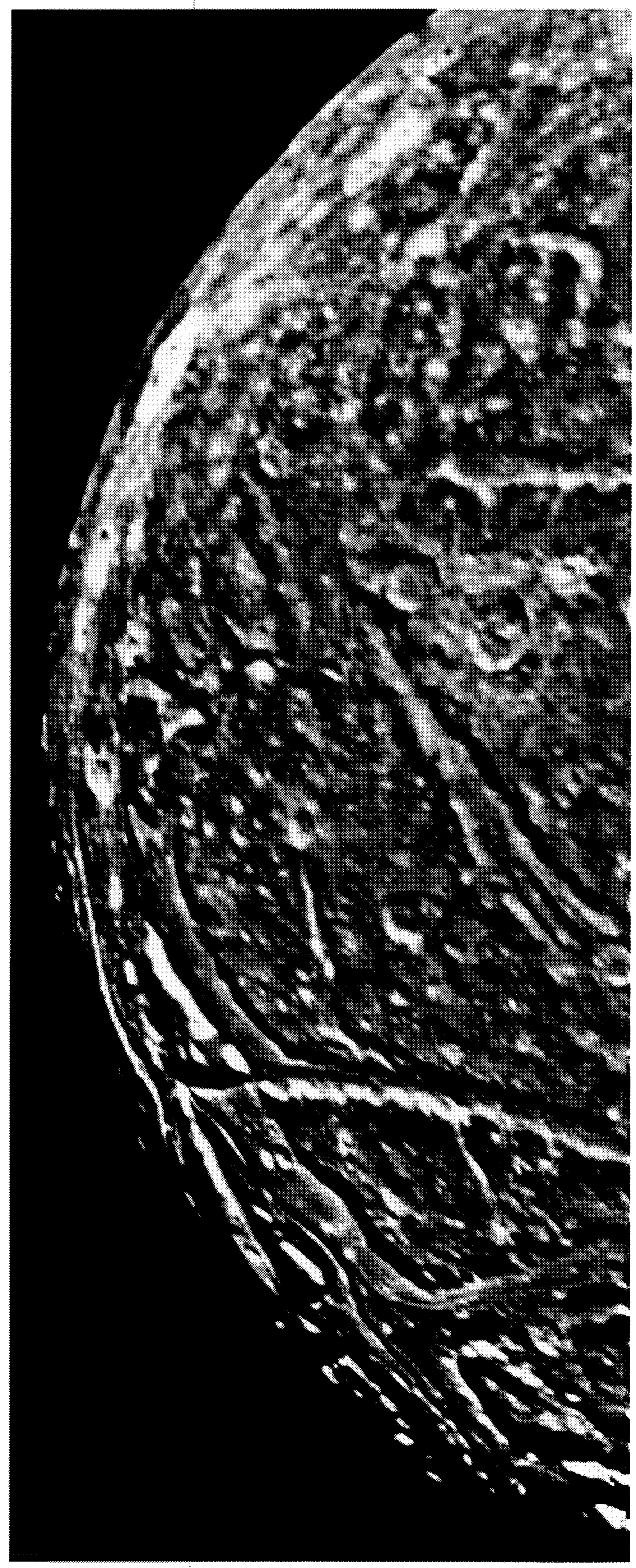


Oberon's icy surface displays several large impact craters. A large peak protrudes 20 kilometers (about 13 miles) above Oberon's lower left limb.



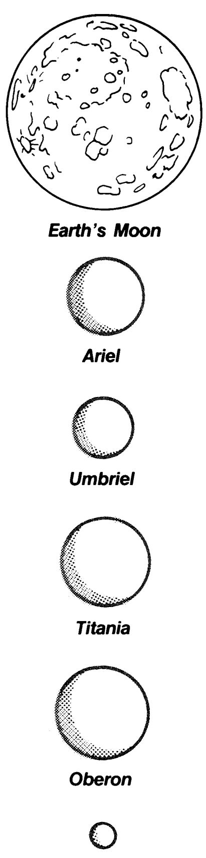
Three of the Uranian moons discovered by Voyager were captured in one photograph, at left. Ariel, at right, has undergone much geologic change, with most evidence of early cratering erased by surface melting and other activity.

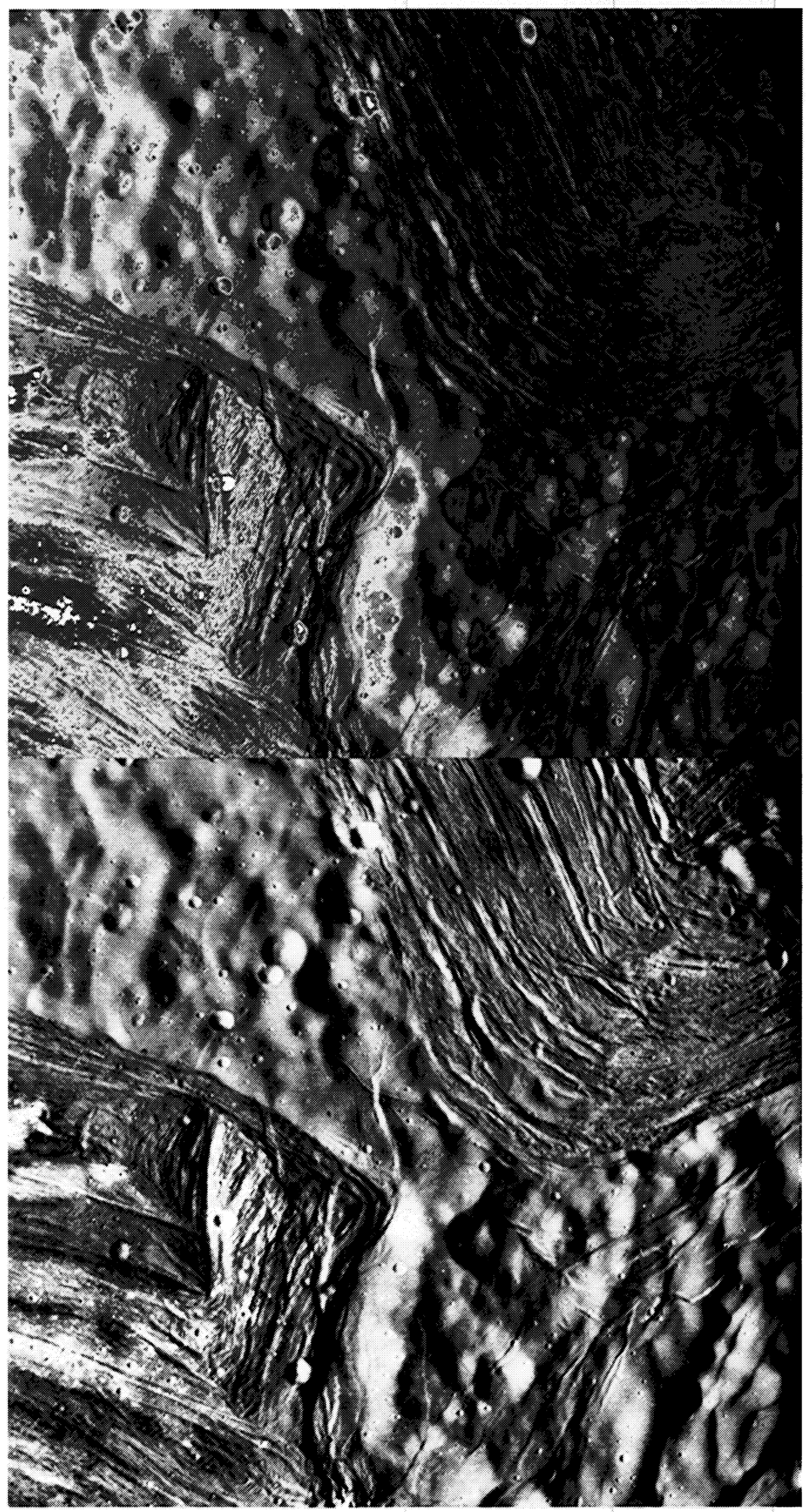




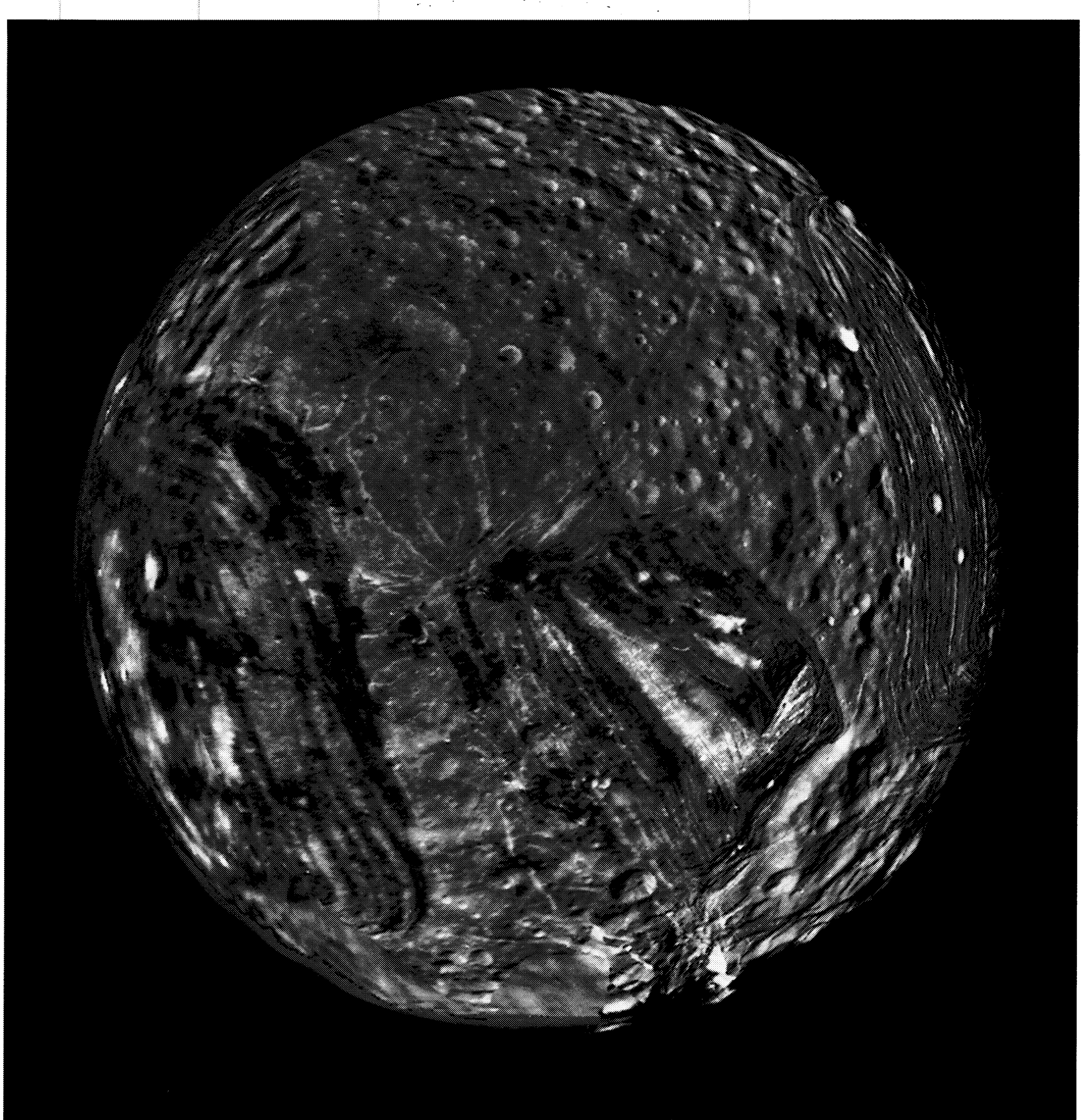
Planetary scientists were not surprised to see the geologically altered surfaces on the Uranian moons. But they were amazed by the tortuously rended face of Miranda, impressed that such a small, cold body had endured so much change. Here was a moon marked by crisscrossed grooves, with parallel fault systems encircling even more complex grooved terrain. Huge canyons—one 20 kilometers (12 miles) deep—slice this tiny moon's surface. Great plates of land appear to have been upthrust, leaving Miranda looking as though it was being spaded by a giant shovel when suddenly, all geologic activity ceased.

Some scientists think Miranda may have been frozen in the midst of a geologic process most terrestrial objects in the solar system underwent at an early age, a process in which the body almost literally turns inside out. Miranda may also be the reaggregated parts of one or more moons that were shattered in a collision or torn apart in a gravitational tug-of-war.





Evidence of a variety of geologic processes is seen in this patch of Miranda's surface. The top image is in false color. The entire picture spans an area about 220 kilometers (140 miles) across.

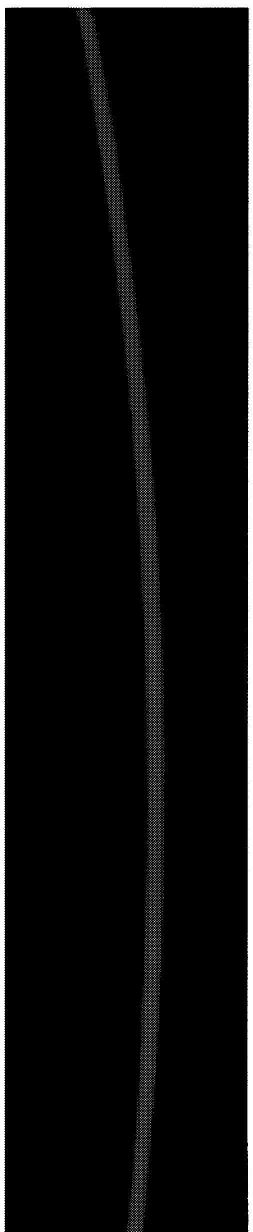


Nine images were combined to create this mosaic of Miranda. The moon's surface consists of two strikingly different types of terrain: old, heavily cratered areas and young, complex regions characterized by scarps and ridges.

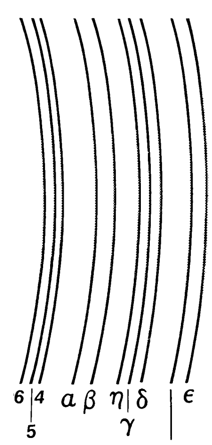
THE RINGS

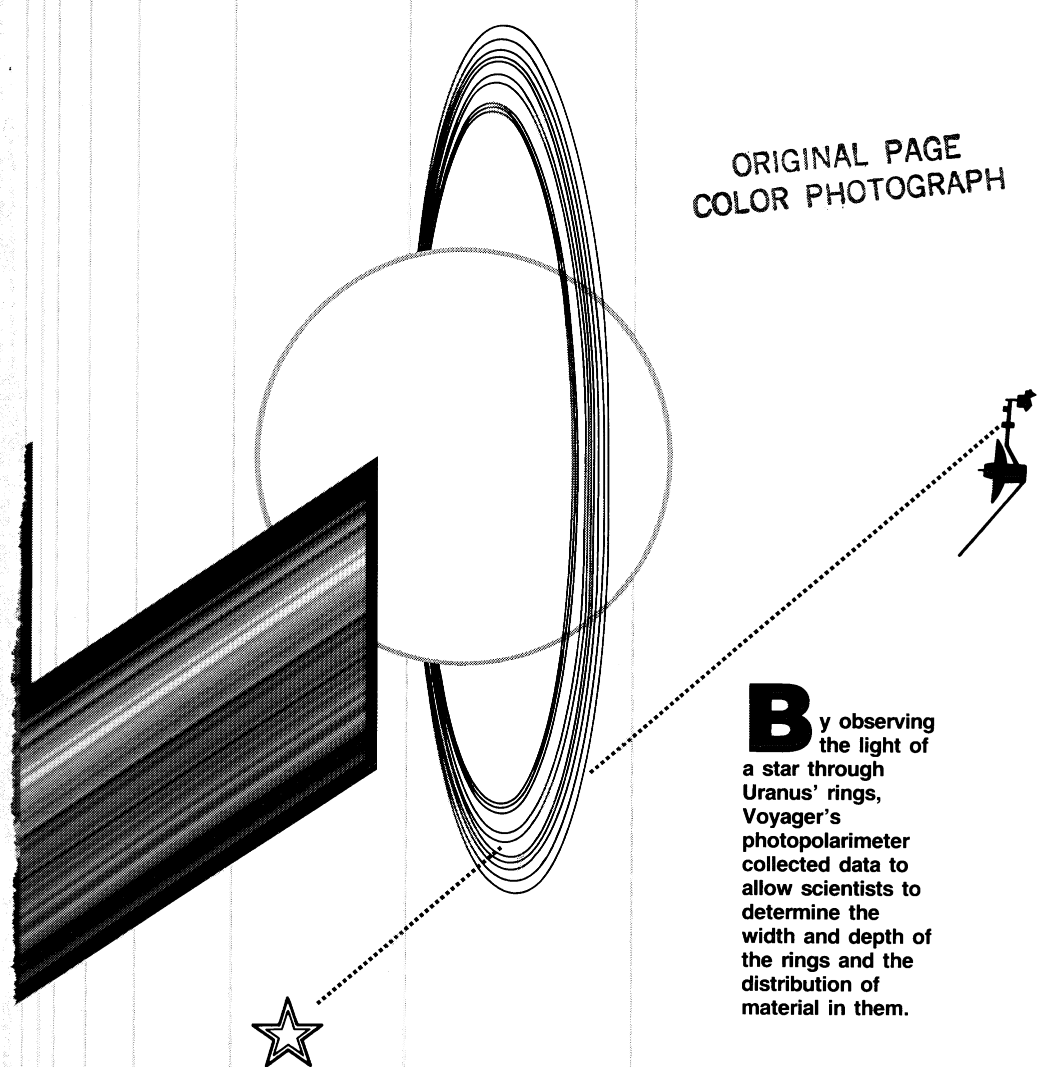
From Uranus' dark, irregular rings, scientists have determined that planetary rings may be short-lived phenomena that come and go throughout a planet's lifetime.

Based on the discovery of shepherd moons in Saturn's rings, Voyager scientists predicted and found small shepherding moons at Uranus that herd particles into strands that form rings around the planet. The particles themselves may be chunks of a moon fractured in a collision.



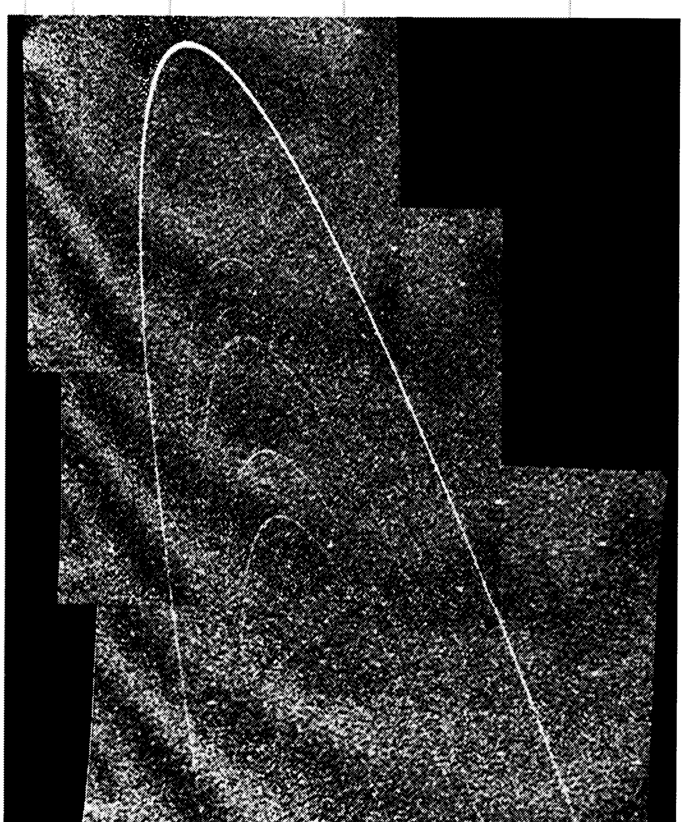
Pictures of the Uranian rings were made from data obtained by Voyager's photopolarimeter. At left is the narrow gamma ring. Four slices of the epsilon ring, above, show the widely varying widths of the ring.





By observing the light of a star through Uranus' rings, Voyager's photopolarimeter collected data to allow scientists to determine the width and depth of the rings and the distribution of material in them.

As the star Sigma Sagittarii passed behind the delta ring, the photopolarimeter recorded the data from which this false-color picture was developed.



This photo was taken as Voyager crossed the plane of the Uranian ring system.

At least two new rings and several partial rings were observed, in addition to the nine known to exist before Voyager arrived.

The outermost ring, called epsilon, contains nothing smaller than fist-sized particles. The other rings also seem to contain few smaller particles, in marked contrast to Saturn's and Jupiter's rings. It is thought that atmospheric drag, due to the extended hydrogen corona that Voyager observed around the planet, causes dust particles to spiral into the planet. But why there are no intermediate, marble-sized particles is a puzzle.

Scientists believe that, in time, the rings may actually vanish. As large ring particles collide and grind down to dust, the dust would be swept from the ring system (again, because of drag). New rings could be formed only by the breakup of the orbiting moons.

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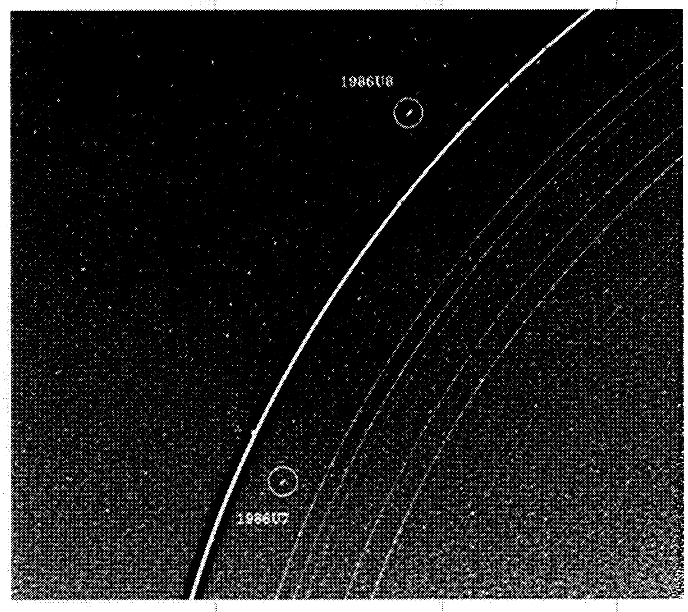
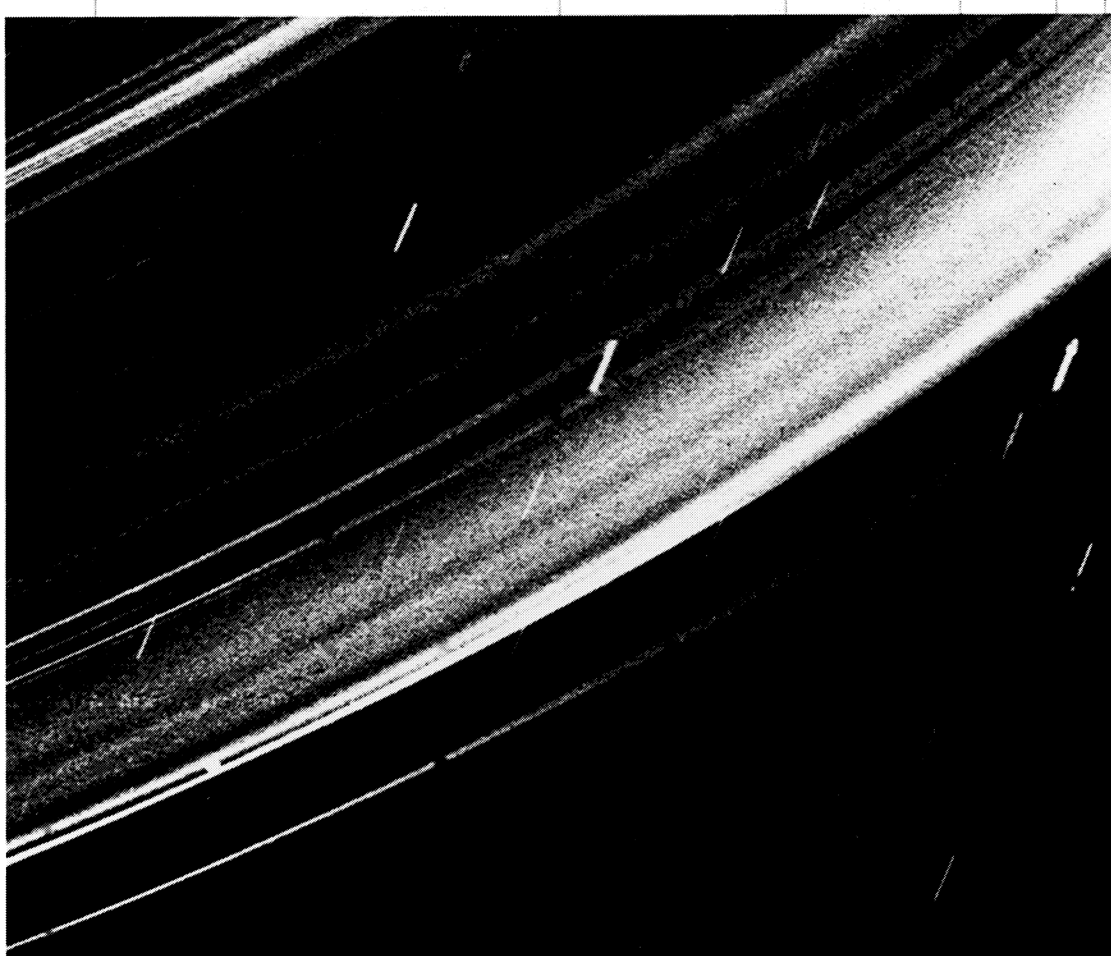
Shepherd moons, as predicted, were found guiding some of Uranus' rings into shape.



This 96-second, wide-angle exposure, taken while Voyager was in the shadow of Uranus, enhances the visibility of micrometer-size particles. The short streaks are smeared images of background stars.



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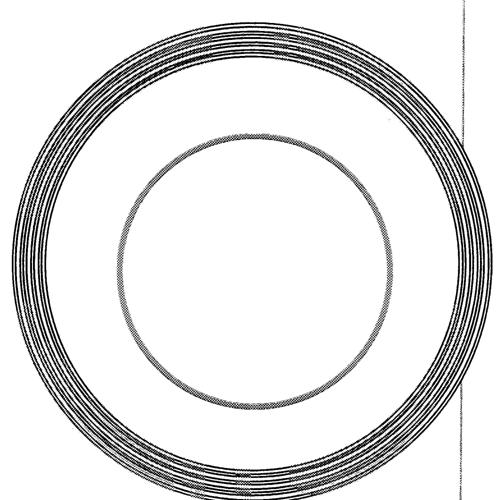


The spaces between Uranus' rings vary from a scant 335 kilometers (208 miles) to 2,877 kilometers (1,784 miles).

Dust and large chunks of rock and ice make up the Uranian ring system.

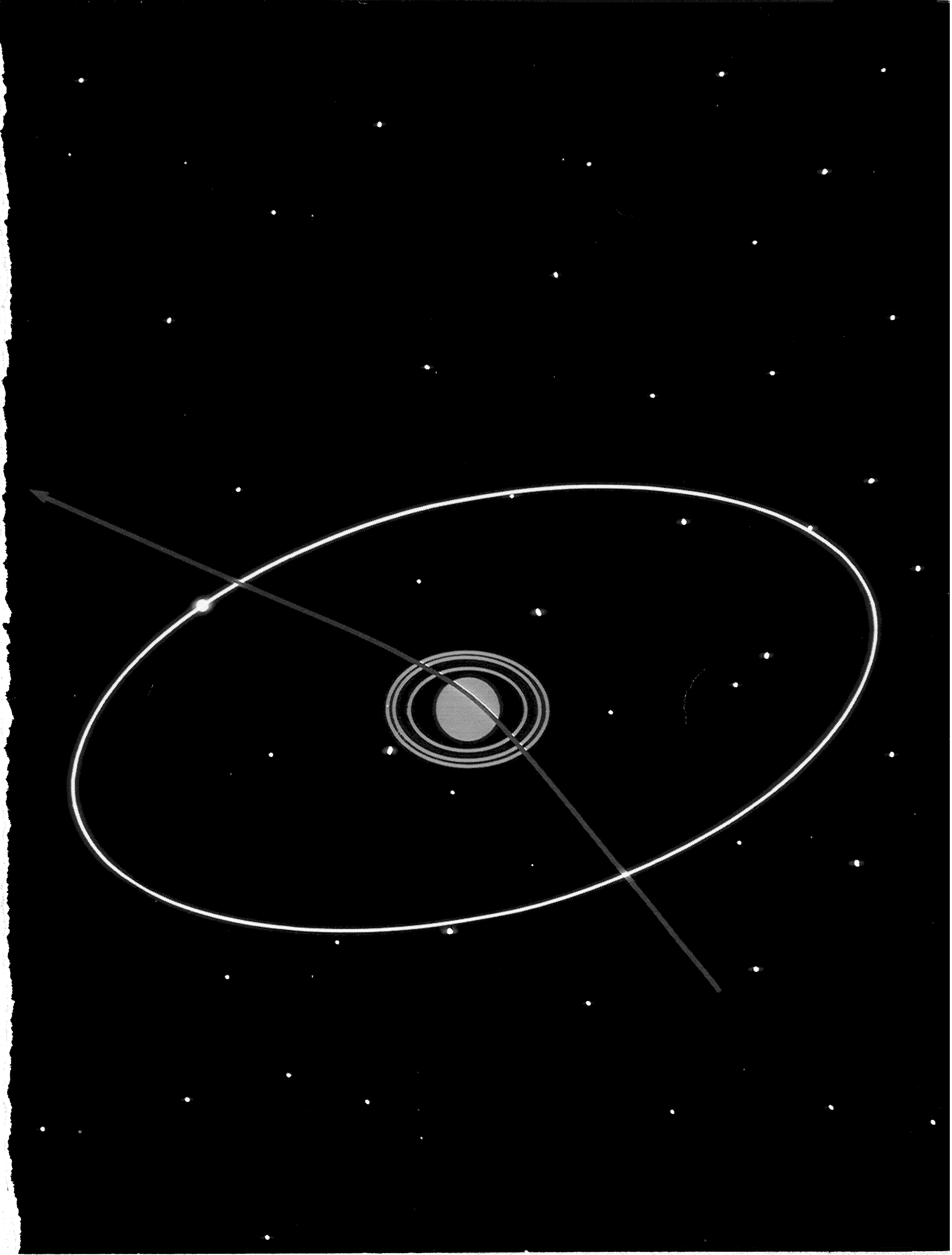
With each successful encounter, Voyager 2's goals have been expanded. After the Uranus flyby, engineers commanded the spacecraft to fire its thrusters for a course correction that aimed Voyager 2 toward its next stop—Neptune. That maneuver allows mission planners the widest range of choices for the spacecraft's precise flight past Neptune on August 24, 1989.

One possible route, known as the "polar crown" mission, would take Voyager 2 over the north pole of Neptune at a distance of only 4,500 kilometers (2,800 miles). The mission would allow for a close flyby of Neptune's large moon, Triton, as well. Other plans call for a more distant flight past the planet. The final choice will depend upon further Earth-based studies of the environment near Neptune and the completion of the next course correction maneuver in 1987.

Neptune, the eighth planet from the Sun, possesses a ring system and one of the largest and most enigmatic moons in the solar system. The same measures taken at Uranus to allow clear, sharp photographs will be exercised at Neptune to obtain pictures of Triton, which is about the size of the planet Mercury, and may harbor a rich, hydrocarbon sludge of organic molecules on its surface.

After Neptune, Voyager 2's objective (as is the case with Voyager 1) is to locate the heliopause, the edge of the influence of the Sun and the outer boundary of our solar system. If the spacecraft's radio and other critical components hold up, JPL engineers expect to stay in touch with Voyager 2 beyond the end of the century.

Right: In 1989, Voyager 2 may fly the polar crown trajectory past Neptune and its large moon Triton, shown here from an angle above the planet.



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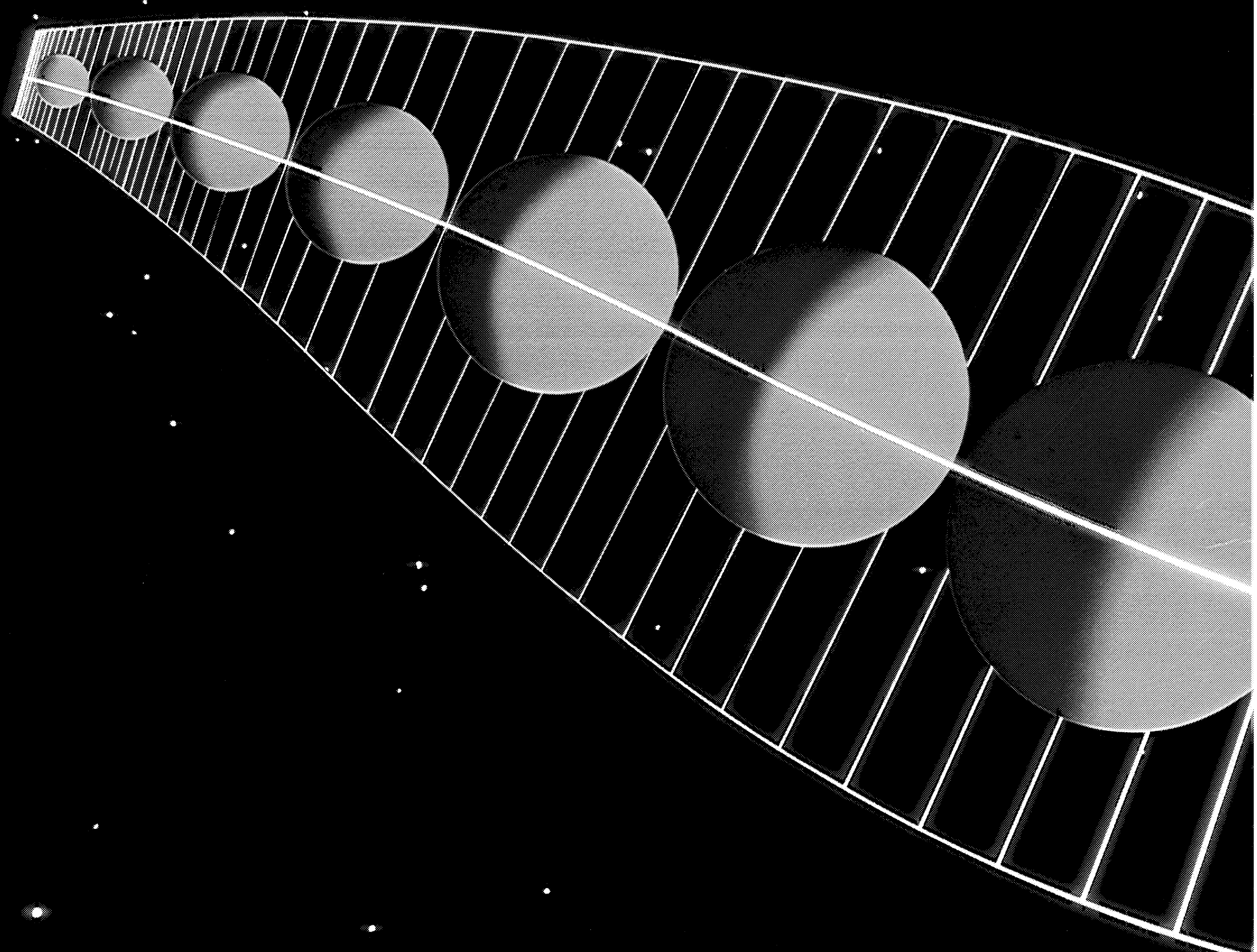

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